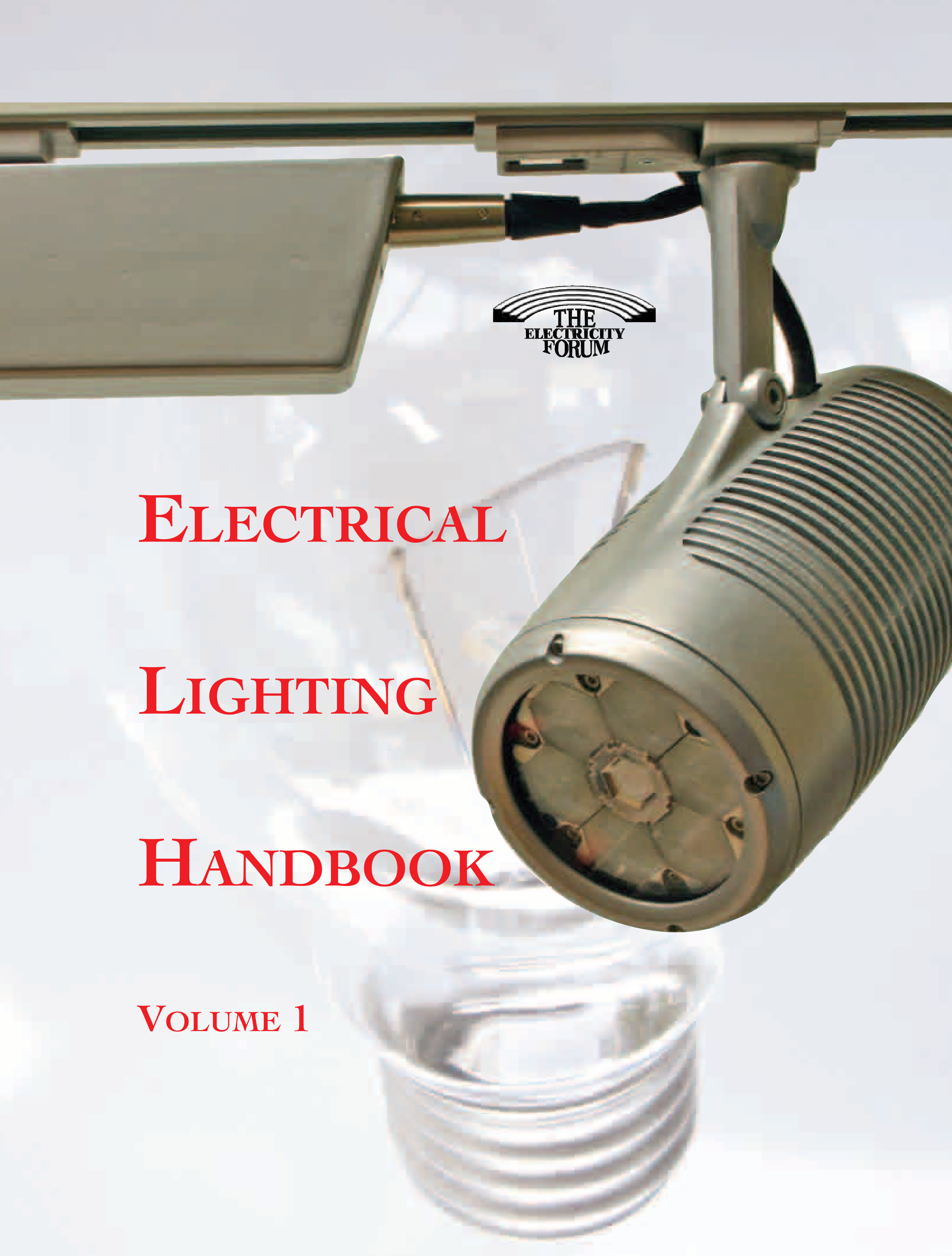

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The Electricity Forum
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Tel: (905) 686-1040 Fax: (905) 686 1078
E-mail: hq@electricityforum.com

The Electricity Forum Inc.
One Franklin Square, Suite 402
Geneva, New York 14456
Tel: (315) 789-8323 Fax: (315) 789 8940
E-mail: forum@capital.net

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VOLUME 1

Randolph W. Hurst
Publisher & Executive Editor

Don Horne
Editor

Cover Design
Don Horne

Layout
Ann Dunbar

Handbook Sales
Lisa Kassmann

Advertising Sales
Carol Gardner
Tammy Williams

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ENERGY POLICY ACT SETS NEW BALLAST EFFICIENCY STANDARDS

By Craig DiLouie, Lighting Controls Association

While new fluorescent ballast efficiency rules went into effect recently, another batch of rules has just been passed that will affect lighting systems starting in 2009. This time, the efficacy standards have been set high enough that the vast majority of magnetic ballasts – including ballasts operating energy-saving T12 lamps – will no longer comply.

In September 2000, the U.S. Department of Energy (DOE) published the Fluorescent Lamp Ballast Energy Conservation Standards (10 CFR, Part 430), which established new minimum ballast efficacy factor (BEF) standards that went into effect starting in 2005. Ballasts that did not pass the standards would be phased out of production and sale in the United States.

Prior to 2005, many believed that this would spell the end of magnetic ballasts. However, it was determined that while magnetic ballasts that operated F40T12, F96T12 and F96T12HO lamps failed the new BEF standards, ballasts designed to operate energy-saving versions of these lamps were not covered by the regulation.

With support from the National Electrical Manufacturers Association (NEMA), the government revisited ballast efficiency in the Energy Policy of Act of 2005 (EPAct 2005), which President Bush signed into law on August 8, 2005. Provisions in EPAct 2005 extend the coverage of BEF standards, which will result in the phased elimination and sale of most magnetic ballasts in new fixtures, including those designed to operate 34W T12 lamps, starting in 2009, and replacement ballasts in 2010.

"There has been some market confusion following the 2000 DOE Ballast Rule as to whether ballasts for energy-saving T12 lamps were subject to the federal minimum efficiency requirements," says Kyle Pitsor, Vice President Government Relations for NEMA. "In response, NEMA championed the effort to seek clarity on the coverage of the ballasts for energy-saving lamps in the drafting and passage of HR 6, EPAct 2005. This change now explicitly covers them, will provide market certainty and will improve energy efficiency."

Below are the current ballast efficacy requirements for ballasts operating F40T12, F96T12 and F96T12HO lamps, which went into effect April 1, 2005:

Ballast-Lamp System	Nominal Lamp Wattage (W)	Voltage (V)	Ballast Efficacy Factor (BEF)
(1) F40T12 lamp	40	120/277	2.29
(2) F40T12 lamps	80	120/277	1.17
(2) F96T12 lamps	150	120/277	0.63
(2) F96T12HO lamps	220	120/277	0.39

Below are the new ballast efficacy requirements for ballasts operating F34T12, F96T12/ES and F96T12HO/ES lamps, which will go into effect July 1, 2009:

Nominal Lamp Ballast-Lamp System	Wattage (W)	Ballast Efficacy Voltage (V)	Factor (BEF)
(1) F34T12 lamp	34	120/277	2.61
(2) F34T12 lamps	68	120/277	1.35
(2) F96T12/ES lamps	120	120/277	0.77
(2) F96T12HO/ES lamps	190	120/277	

In review, BEF is calculated: (Ballast Factor * 100) / System Watts). The higher the number, the more efficient the ballast must be to meet or exceed it.

Below are the two timetables governing the phased withdrawal of ballasts that do not meet the new BEF standards:

Action	2005 BEF Standards for Full-Wattage T12 Lamps	2009 BEF Standards for Energy-Saving T12 Lamps
Ballast manufacturers can no longer make ballasts that do not pass the new requirements for use in new fixtures.	April 1, 2005	July 1, 2009
Ballast manufacturers cannot sell ballasts that do not pass the new requirements to U.S. fixture manufacturers.	July 1, 2005	October 1, 2009
Fixture manufacturers cannot sell fixtures that include ballasts that do not pass the new requirements.	April 1, 2006	July 1, 2010
Ballast manufacturers cannot manufacture replacement ballasts that do not pass the new requirements.	July 1, 2010	July 1, 2010

Both ballast rules exempt ballasts that:

- Are designed for dimming to 50 percent or less of their maximum light output
- Are designed for use with two F96T12HO lamps at ambient temperatures of -20 ° F and for use in outdoor signs
- Have a power factor of less than 0.90 and are designed and labeled for use only in residential applications.

Replacement ballasts will continue to be manufactured and sold until July 1, 2010. These ballasts will feature output leads shorter than the length of the lamp they operate, may be shipped in packages limited to 10 or fewer units, and will be marked, for replacement only.

While this legislation is significant, the market has rapidly adopted electronic ballasts for new fixtures in the last decade. According to the U.S. Economic Census, electronic fluorescent ballasts represented 47 percent of U.S. sales at the time the regulation was published in 2000; in 2002, they represented 57 percent of all ballasts shipped in the U.S. One ballast manufacturer, using preliminary Census Bureau data, estimates that they exceeded 60 percent in 2003. At the current rate, by 2010, magnetic ballasts in new fixtures may become much of a dinosaur anyway due to commercial market preference for electronic ballasts.

A significant element of both the original 2000 ballast rule and the new rule included in EPAct 2005, however, is the gradual elimination of the manufacture and sale of replacement magnetic ballasts for full-wattage and energy-saving F40T12, F96T12 and F96T12HO lamps. Building owners will have to retrofit or gradually replace their magnetic ballasts with higher-efficiency ballasts as they fail.

"EPAct 2005 contains a number of provisions of interest to the lighting community," says Pitsor. "These include new lighting products subject to federal efficiency standards, new tax deduction provision that benefits lighting energy-efficient commercial buildings, establishment of a solid state lighting program at the DOE, and promotion of ASHRAE and IECC standards."

CHANGING WHITE LIGHT

Ian Ashdown, FIES, Senior Research Scientist, TIR Systems Limited

Now that we have solid state lighting that can generate white light with changeable color temperature, what can we do with it?

Solid state lighting has given us something new: the ability to generate white light with changeable color temperature. The principle is simple: blend the light generated by warm white and cool white LEDs or vary the proportions of light emitted by red, green and blue LEDs. The result is… magical. Lighting designers who have seen it are entranced by the possibilities.

We spend much of our lives indoors under fluorescent or incandescent lighting. If we are fortunate, we enjoy some daylight through windows or skylights, but otherwise we are disconnected from the outside environment. This is regrettable, as our moods and psychological states are influenced by the daily cycle of sunlight and skylight. What if we could not only dim the lighting but also change the color temperature to follow the daily cycle or to suit our moods?

This idea is not new – there are U.S. patents dating back to 1996, and at least one European manufacturer (www.spectral-online.de) offers direct/indirect pendant luminaires and luminous ceilings with color temperatures that can be varied from 3,000 to 10,000 Kelvin. However, the idea becomes truly practical with solid state lighting.

PEOPLE – WHAT CAN WE DO WITH IT?

There is no question color temperature influences our perception of the visual environment. In 1941 A.A. Kruithof conducted an informal pilot study for the Philips Research Laboratory in which he concluded the following:

- Observers prefer lower color temperatures at low light levels, and higher color temperatures at high light levels;
- Low color temperatures at high light levels make the environment appear artificial and overly colorful; and
- High color temperatures at low light levels make the environment appear cold and dim.

He further produced the “Kruithof effect” chart shown in Figure 1.

If you read Chapter 3 of the IESNA Lighting Handbook, you will find there is scientific evidence both for and against the existence of this effect. In particular, some researchers have noted that Kruithof likely used fluorescent lamps with low color rendering indices (CRIs), and so his results may have been influenced by the observers’ color preferences. Other researchers have noted that the effect disappears after the observer adapts to the color temperature of the light source.

On the other hand, these more exacting studies have necessarily been performed using luminaires with the same color temperature. Most environments have a complex mix of fluorescent and incandescent lamps, not to mention daylight entering through windows and skylights. In such situations, our adaptation is constantly changing as we shift our attention from one visual task to another. Scientific studies notwithstanding, the Kruithof effect is likely relevant to some extent for everyday visual environments.

The key phrase, however, is “color preference”. Our color preferences are notoriously difficult to measure in the laboratory, let alone quantify as a lighting design rule. As such, Figure 1 should be viewed as an informal design guide, to be interpreted with due consideration of other knowledge and design experience.

Fluorescent lamp sales have consistently shown that consumers in the southern United States prefer cool white lamps for residential use, while those in more temperate climates prefer warm white. Similarly, consumers in India and other tropical climates prefer cool white. This makes intuitive sense in that people in temperate climates seek a sense of warmth for their homes, while those in tropical climates seek relief from the heat. (See, however, the sidebar The Language of Color for another possible explanation.) Even if the Kruithof effect is discounted, something is determining consumer preferences.

If you choose to design with Figure 1 as a guideline, you should keep chromatic adaptation in mind. If the color temperature of the lamps illuminating an environment suddenly changes, we initially perceive both the light sources and white surfaces as being either yellowish or bluish in color (depending on the change in color temperature). After about sixty seconds, however, our visual system adapts to the change and we see the light sources and white surfaces as being white again.

Depending on the skill of the lighting designer, this can be a good situation. Mixed illumination can result in visually interesting and pleasing environments. Having the ability to dynamically change the color temperature provides the designer with a new palette of lighting design options. Think of high-end residences, long-term care facilities, restaurants, hotel lobbies and retail store displays as possibilities. These environments already make good use of dimmable incandescent lamps; solid state lighting with changeable color temperature greatly expands the design opportunities.

Consider the reception desk in a hotel lobby. If there is a considerable amount of daylight entering the lobby, the color temperature of the luminaires illuminating the desk can track or otherwise complement the spectral distribution of the daylight. High color temperatures during sunny days may be appropriate, but cloudy days with rain may benefit from warm color temperatures to offset the mood of the inclement weather.

What about long-term care facilities? Rather than spending endless hours under constant illumination, residents may enjoy recreational spaces in which the lighting intensity and color temperature vary throughout the day. It may be easy to overdo the effect with faddish lighting, but subtle lighting changes may provide welcome relief from the monotony.

LIGHTING RESEARCH – WHAT ABOUT IT?

There are numerous scientific studies concerning color temperature and color preferences that demonstrate the importance of temperature. For example, warm color temperatures apparently encourage people to resolve interpersonal conflicts through collaboration rather than avoidance, while cool color temperatures make it easier to read printed books and papers. Interestingly, it is the surround light in our peripheral vision rather than the task lighting that most influences our visual acuity. This implies that we can have warm white task lighting for reading (warmth and comfort) with cool white ambient lighting (bright and cheerful).

A more complex issue is whether simulating the daily cycle of sunlight and skylight with changes in both light levels and color temperature is beneficial for night shift workers. A study done by the Lighting Research Center (www.lrc.rpi.edu) in 1997 found that mimicking changes in daylight intensity and color temperature improved workers' ability to handle mentally demanding tasks throughout eight-hour night shifts. However, the study did not attempt to separate the influence of changes in intensity and color temperature.

The Lighting Research Center has since been particularly active in studying the relationship between lighting intensity, spectral power distribution, and circadian rhythms (e.g., "Research Matters," LD+A, May 2006). In brief, our retinas convert light into neural signals that regulate our bodies' sleep patterns and wakefulness. Whether mimicking the changes in daylight color temperature has an effect on circadian rhythms is apparently an open question. If it does, then this may be useful in designing lighting system for night-shift workers and control-room operators.

There is, however, a caveat to interpreting lighting and vision research for design guidelines. Many experiments necessarily involve simplified visual environments that attempt to isolate and study single factors. However, we live and work in visually complex environments, and it is precisely these confounding influences that affect our overall perception and mental states. Therefore, it is best to consider research results as points of reference when making design decisions, and as a possible explanation when a particular design succeeds or fails.

DISPLAYS – WHAT ARE THE USES AND BENEFITS?

Displays are an obvious candidate for solid state lighting. Gold jewelry, for example, looks best when illuminated with warm white light because it emphasizes the yellow highlights. Silver jewelry, on the other hand, looks best under cool white light because silver highlights are spectrally neutral. Having controllable color temperature enables the shop owner to easily tune the lighting digitally as needed to best showcase the items on display.

More generally, most art galleries and museums currently choose incandescent light sources with a color temperature of 3000 K to illuminate their displays. However, several small-scale studies have shown that viewers prefer lighting with slightly higher color temperatures (around 3600 K) because it maximizes the chromatic diversity of the artwork. More generally, higher color temperatures are preferred for works of art with predominant blues and violets, while lower color temperatures are preferred for predominant yellows and reds.

Other advantages of higher color temperatures include increased color saturation, a greater sense of depth (due to the effects of chromatic aberration in the human eye), and improved brightness and clarity. This must be balanced, however, against the intentions of the artist or sensibilities of the museum curator.

As an example, landscape paintings that are painted outdoors are illuminated with perhaps 20,000 lux and color temperatures ranging from 5,000 to 15,000 Kelvin. When they are viewed indoors with electric lighting, incandescent lamps may provide 200 to 500 lux. It is perhaps not a coincidence that the preferred color temperatures follow Kruithof's recommendation of 3,000 to 3,500 Kelvin.

Perhaps the best feature of solid state lighting for displays is that the color temperature can be easily changed independently of the intensity, and without the need for color correction filters or constant ladder time by maintenance staff. Other benefits include complete freedom from damaging ultraviolet and infrared radiation.

SPECIALTY LIGHTING – WHO NEEDS WHAT?

There are numerous niche applications that can benefit from controllable color temperature. Trumpf Medical Systems (www.trumpf-med.com) has recently introduced LED-based surgical lights that allow the surgeon to change the color temperature according to the type of procedure being performed. Warm white light (3,500 K) is useful for examining skin and light tissue parts, while cool white light (6,500 K) is preferred for viewing internal organs and performing lengthy surgical procedures. Higher color temperatures are also preferred for minimizing eyestrain and maintaining concentration.

The same principle will likely apply to any craftsperson involved in visually demanding tasks that require lengthy periods of concentration, from hand-sewing to diamond-cutting. A high color temperature in the surround light causes our pupils to contract, which improves the depth of field and reduces spherical and chromatic aberrations in the eye. We also perceive the illumination as being brighter than low-color-temperature lighting. However, being able to change the color temperature on demand enables the user to view the object under normal indoor lighting conditions when desired.

Finally, dentists prefer high color temperatures because it is easier to identify caries during examinations and to differentiate dentin from enamel when performing dental work. At the same time, they need to match porcelain crowns and composite resin fillings with tooth coloration. Having the ability to vary the color temperature could be a valuable asset.

CONCLUSIONS

Solid state lighting providing white light with changeable color temperature is something new. Like all new technologies, lighting designers need to learn from experience what works and what does not. We will undoubtedly see signature applications that will capture our attention today, but which in five to ten years' time will prompt us to ask, "What were we thinking?"

More likely, however, we will discover applications for white light with controllable color temperature that will in five to ten years' time prompt us to ask, "How did we ever live without it?" It is a new capability for professional lighting design, and ours to discover.

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THE LANGUAGE OF COLOR

Professional lighting design is based on experience and knowledge. Faithfully reading the lighting design journals to keep up to date is essential, but it sometimes pays to look farther afield.

Consider, for example, the fact that consumers in tropical climates prefer cool white fluorescent lamps, while those in temperate climates prefer warm white fluorescents. This is usually explained in terms of color temperature affecting our mood and mental state, but perhaps there is another explanation.

The difference between warm white and cool white light is that the latter has more blue light. If people in tropical climates were less sensitive to blue light, they may perceive warm versus cool white illumination differently from residents of temperate climates.

Support for this hypothesis comes from an unusual source: linguistics. When two vision researchers (Lindsey and Brown, 2004) analyzed a study of 2616 speakers of 110 tropical languages, they found that distinct names for the color "blue" rarely occur in their vocabulary. Instead, blue is considered to be a shade of green. However, most languages have distinct names for black, white, red, yellow and green. They concluded that this made sense if the color blue was "insufficiently important to all speakers of a language for them to give distinct names to all the colors they can distinguish." (What the researchers did not consider is that this included many Indo-European languages until quite recent times – see Pastoreau's fascinating book, Blue: The History of a Color.)

Their explanation for this situation is quite logical. Our corneas tend to yellow as we age due to ultraviolet degradation, and the prevalence of harmful ultraviolet radiation is greater in the tropics. The color blue is presumably not important to speakers of tropical languages because most adults may have difficulty distinguishing blue from green. (Elderly people in temperate climates have similar difficulties.)

Whether this is true remains to be experimentally verified. If it is true, then much of our quantitative understanding of color vision may need the caveat, "not necessarily applicable in tropical regions." This may be important for solid state lighting, as lighting researchers have concluded that the CIE color rendering index (CRI) does not accurately represent observers' color perception when viewing white light generated by red, green and blue LEDs. Will we have to differentiate adult observers from temperate and tropical climates?

For lighting researchers, more research is required. For lighting designers, this is an example of finding possible design ideas in the most unlikely of places.

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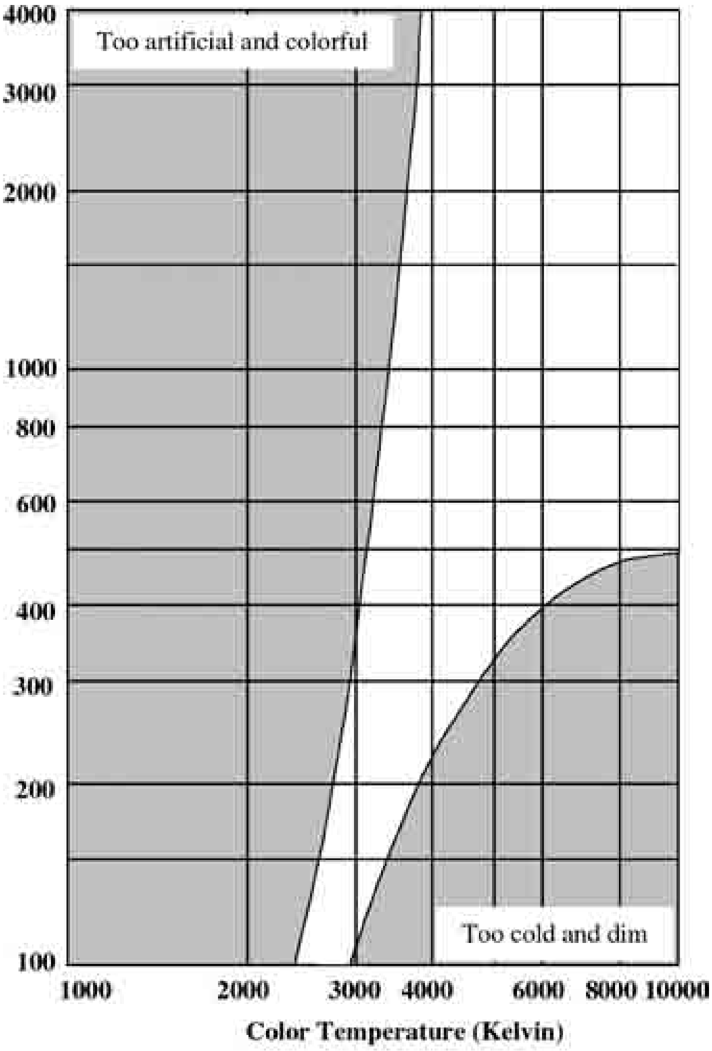


Figure 1. Kruithof Effect – Color Temperature versus Illuminance

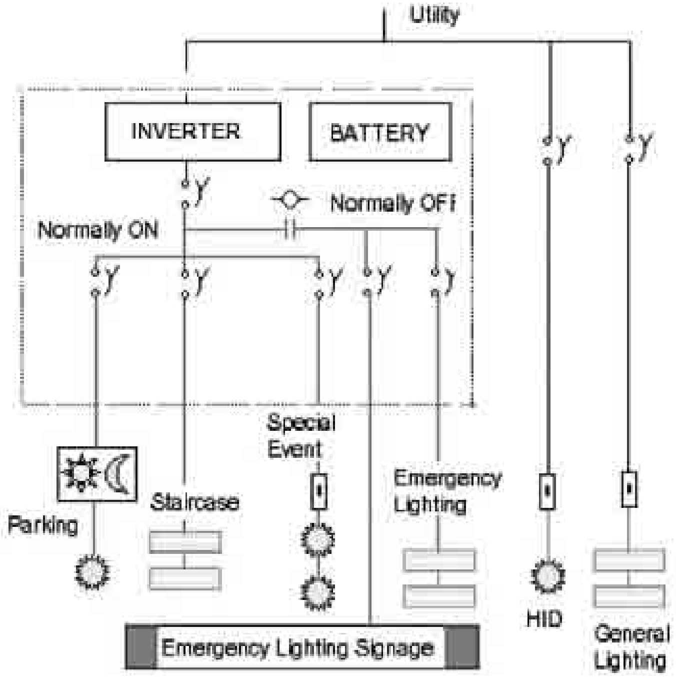
Figure 2A. 3500 Kelvin illumination

Figure 2B. 6500 Kelvin illumination

APPLYING CENTRALIZED EMERGENCY LIGHTING INVERTER SYSTEMS

Controlled Power Company

Centralized Emergency Lighting Inverters offer a wide variety of applications and versatility in lighting operations. They provide simplified maintenance, central monitoring and mandated monthly testing all in one location. An inverter, that includes voltage regulation, can feed more floors and serve greater distances because the minimal voltage drop of the feed wire is the only diminishing factor. Overall, the ROI when using an inverter is great. Special lighting fixtures, general lighting, point of egress, aesthetic lighting, HID and more are all compatible with the Controlled Power EL Series emergency lighting inverters.



Permanent lighting for areas that have no occupancy control, such as staircases, large public bathrooms etc. would be connected to the inverter because these areas are typically illuminated 24/7 and represent a point of egress. (Bathrooms may use small self-contained backup lighting. But remember the 30 day test; more maintenance.)

Emergency lighting is the required lighting that must meet the standards for signage and lumens in occupied areas. These must be connected to a back-up system! Here is where an inverter excels. On location of dedicated power for all the requirements!

EMERGENCY POWER

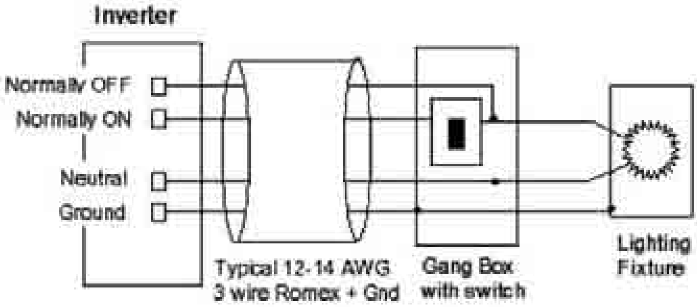
Emergency Power is also broken down into categories:

Permanent no-break (normally ON) uninterrupted power used for permanent lighting is the only type of inverter that can be used for HID, High Pressure sodium lamps, mercury vapor and metal halide.

Switched Power (normally OFF) is power that only comes on when there is a power outage. Signage and additional lighting would typically be connected to this function.

Time Delayed Switched Power provides a means of preventing unnecessary activation of the emergency lamps. Typically, inverters will supply emergency power within a few thousandths of a second upon sensing that the incoming power is out of specification limits. Recorded data indicates the greatest number of outages last less than four seconds. There is no need to bring up the emergency lighting for these cases. It only causes confusion among the occupants. By delaying the emergency power 5 to 9 seconds, then only true power outages will activate the emergency lighting.

Timed Delayed Return Power is an inverter function that keeps the emergency power operational for a preset time after normal power is restored.



The time delay return function is programmable to coincide with the start-up time of HID, High Pressure sodium lamps, mercury vapor and metal halide lamps. It provides an automatic means of assuring that areas illuminated by these types of lamps will always have light.

Controlled Power Company's broad line of lighting inverters offer a method to accomplish all of these functions.

SPECIAL CASES

There are special cases where the parts of general lighting will serve as the emergency lighting. Under these circumstances, the lamps used for emergency lighting, are connected to both "Permanent no-break (normally ON)" power and the "Switched Power (normally OFF)" power. The occupant may turn the lighting on-off at his convenience, but in the event of emergency power requirement, the inverter will automatically override the circuit and supply power directly to the lamp(s). This approach requires an additional wire from the inverter to bypass the local control device.

Note: Drawing is conceptual. For info concerning overcurrent devices reference NEC and local codes.

WITH A FLICK OF MY BIC

Richard P. Bingham, Dranetz-BMI

Flickering of the lights in an office, factory, or residential home isn't a new power quality phenomena, but is one that is receiving more attention lately.

Historically, flicker has not received the same attention that sags and transients have, as the voltage fluctuations that result in the light flickering generally do not interrupt a process or cause equipment failures. However, as businesses realize that their employees are their most valuable assets, keeping those "knowledge assets" running at full productivity is increasingly important. Some people are reconsidering the "sick building syndrome" as not always being related to the air quality and the HVAC system, but the "silent nauseator". The flicker phenomena can be so subtle enough as to not be consciously detected by those effected, but can induce discomfort, nausea, and in extreme case, epileptic seizures.

Working with a number of electric utility power quality engineers in the past year has revealed a number of cases where they tried to solve customer complaints of blinking lights with all of the traditional methods and tools, without success. Most conventional power quality monitors are not capable of detecting the relative small voltage modulations or variations in amplitude at subharmonic frequencies (below 30Hz) that result in light flicker. It either takes a flicker meter or special software, such as the Flicker TASKCard for the Dranetz-BMI Power Platform, to properly detect and determine the source of the flicker.

WHAT IT IS

- flicker is the perceived change in light output from a lamp,
- caused by the fluctuation of the supply voltage in the frequency range of 0.5 to 30 Hz
  - as little as a quarter of a percent voltage fluctuation at 9Hz can be perceived
- voltage fluctuations or modulations of the RMS envelope
  - follows the same basic rules as the RMS variations that result in sags (dips) or swells.
- usually the result of a change in load current
  - which causes a change in the voltage drop across the source impedance,
  - which then results in a change in the voltage supply
- The frequency of the voltage fluctuation can be
  - the direct result of the frequency of the current draw by the load
  - the result of folding back of higher frequencies modulating with 50/60 Hz fundamental or their harmonics, which produces sidebands around the fundamental or harmonic frequency

FACTORS AFFECTING SEVERITY

- frequency of the voltage fluctuation (how often it occurs)
- magnitude of the voltage fluctuation (how much of a change)
- type of lighting (incandescent, fluorescent, HID)
- ambient light level
- amount of the surface illuminated,
- type of activity and the eye-brain characteristics of the individual person

EFFECTS

- normally perceived as an annoyance and distraction.
- may induce discomfort in the form of nausea or headaches.
- usually are not severe enough to disrupt most manufacturing processes, though
  - may cause different colors (light shades) of woven fabric
  - may vary pipe diameter in plastic extrusion processes.

HOW IS IT MEASURED

The perception of the light flickering is usually measured by two parameters, Pst and Plt.

- Pst is the short term perception index
- Plt is the long term perception index
- A value of 1 being assigned to the lower bound of the observable flicker perception curve for 60W incandescent light bulbs
- The larger the number, the more perceptible it is

Monitoring for flicker is usually done for these reasons:

- determining the source
- determining compliance with limits
- generally begins at the point of common coupling
- change in current vrs change in voltage help determine upstream or downstream from the source

SOURCES

Common sources of flicker include:

- lamp dimmers
- resistance welding machines
- rolling mills
- large electric motors with variable loads
- arc furnaces and arc welders
- switching on and off of PF correction capacitors
- medical imaging machines (X-ray, MRI, CAT Scan)
- large capacity copy machines
- motors in heat-pumps or air conditioning, including refrigerator chambers for meat storage
- household appliances

SOLUTIONS

- reducing the magnitude and/or changing the frequency of the current draw
- reducing the source impedance
- changing the type of lighting

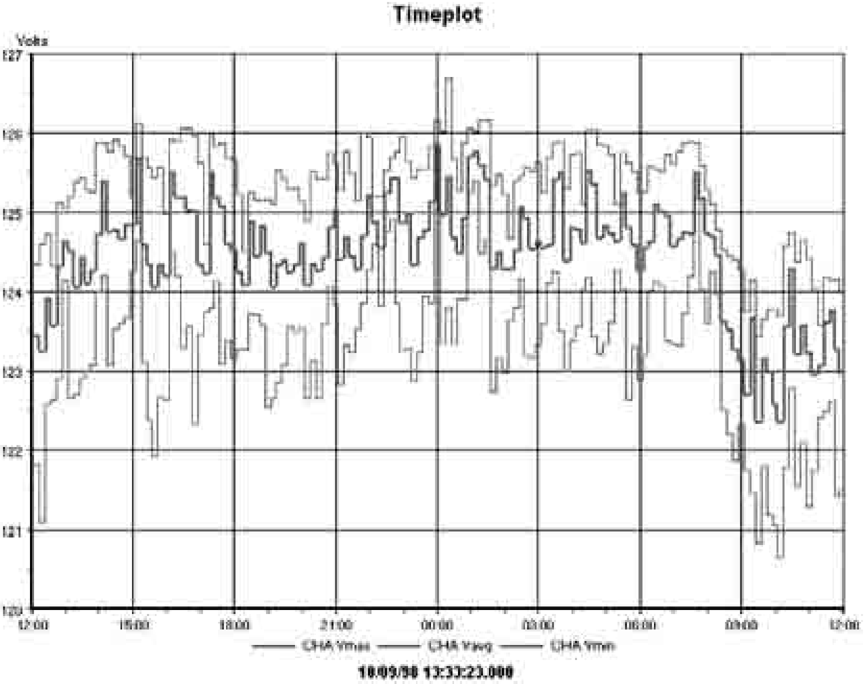
STANDARDS

In the United States,

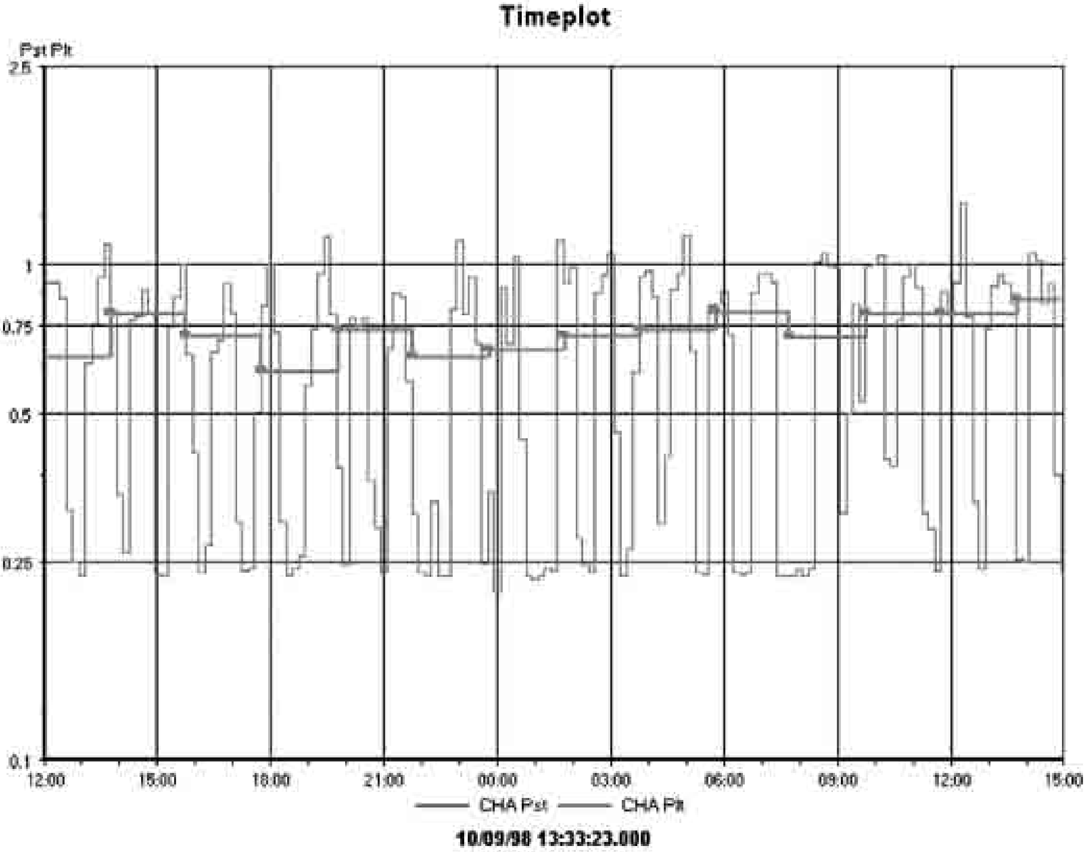
- IEEE/ANSI Std 141 Recommended Practice for Electric Power Distribution for Industrial Plants (the Red Book)
- IEEE 519-1992 Recommended Practice and Requirements for Harmonic Control in Electric Power Systems
- based on work by General Electric in the 1930's, and Westinghouse and Consolidated Edison in the late 50s

The European community places limits flicker as "value to be less than the limit for 95% of the time".

- UIE "Flicker Measurement and Evaluation" document in 1986
- IEC 868 (1986), "Flickermeter, Functional and design specifications" and the IEC 1000-4-15
- IEC 1000-3-3 and EN6100-3-3 address limits on voltage fluctuations and flicker.
- US-based standards groups adopting compatible documents as standards.



Voltage modulation (Vmax, Vaverage, and Vmin) vrs the Pst and Plt values were measured on a 120V single phase circuit inside a facility that resulted in light flicker. The cause was an electric arc furnace located 12 miles away, fed from 230 KV circuit. Note the 74 minute cycle time of the arc furnace, which is clearly visible in the Pst graph, but difficult to detect in the Vrms plot.



HARVESTING UNTAPPED HVAC ENERGY SAVINGS IN UNOCCUPIED ROOMS

Steve Campbell

Hotel operation and management is a competitive and price-sensitive industry, with consumers shopping and comparing prices constantly to find the best value. Since room rates cannot be raised very easily in such a competitive environment, cost reduction is often the primary means of increasing margins and profits. After labor costs, HVAC expenses represent the most significant portion of the annual operating budget for hotels, motels and residential suites.

In fact, lights, television sets and HVAC systems operating unnecessarily in unoccupied rooms represent a significant untapped area of cost reduction for hotels – and could be as much as 20% of the building's annual electricity budget. Spiraling energy costs, compounded by seasonal traffic and guests who often leave appliances and lights on, put significant pressure on the hotel's energy management budget – and profit margins. In addition, given the social need to reduce energy consumption globally, many building owners are searching for ways to reduce the environmental "footprint" and impact of their buildings.

The management of the award-winning 162-room Holiday Inn Hotel & Suites in North Vancouver, B.C. spent three years searching for an appropriate energy management system that would reduce their HVAC energy consumption and overall environmental impact without negatively affecting guest comfort. In 2004, four years after the hotel was opened, Energex's energy management software system was installed to monitor and manage hotel HVAC energy consumption. The new system included the installation of occupancy-sensing hardware in each guest room. The hardware in all 162 rooms was networked with the main EMS to deliver real-time monitoring and control capability over each room's energy consumption.

The new energy management system became fully operational in November 2004, with an evaluation conducted over the subsequent twelve-month period. Installation was relatively simple, with contractors using the existing in-room thermostat to connect to the EMS in the building manager's office. Occupancy sensors (one RK410 sensing device per room) were installed. No major contracting work was required to install the system and installation took place over eight days. Monitoring is conducted on a PC platform and no upgrade is required.

Once installed, the Energex EMS operates continuously to monitor occupancy of all rooms on an ongoing basis. The system automatically reacts to an unoccupied room by adjusting the heating or AC according to pre-programmed parameters set by the building manager. For example, when the sensor detects that no guest is present in the room after 15 to 30 minutes, the system will lower the room temperature to "economy" mode and then back to the most comfortable temperature immediately upon sensing an occupant.

Since the system is enabled for continuous monitoring and reporting, it was relatively easy to compare it month-by-month to the previous year's energy consumption patterns. Reports can also be triggered at any time for individual rooms and floor, and by season or day of week – opportunities for additional detailed analysis that can lead to further harvesting of energy savings.

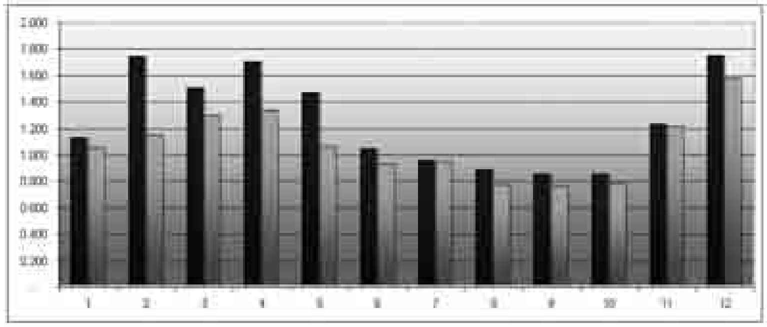
With energy conservation an important mandate of the local utility provider, BC Hydro personnel were closely involved in the study during the set-up phase, and monitored and analyzed all study results to ensure accuracy and evaluate the EMS's suitability for use by other utility customers.

In addition to the direct energy cost savings, the hotel can achieve other long-term cost benefits, in the form of lower maintenance and repair costs in HVAC equipment, reduced wear and tear, and decreased noise build-up and room humidity. While no cost estimate was conducted for these factors, the EMS staff believe the system can help extend the life of HVAC equipment by up to three years through the reduction in routine system wear and tear alone.

The study also found that the Energex system has the ability to use the sensors to report each room's occupancy status to hotel staff members – in real time – via wireless handhelds. For example, by using a handheld wireless unit outside a room door to contact the EMS, housekeepers and maintenance personnel can quickly detect internal occupancy without having to knock on doors and disturb guests unnecessarily. In addition, the units can be used to direct workflow around guests' comings and goings much more efficiently.

An unexpected bonus of the system implementation, according to the hotel management team, was the virtual elimination of guest complaints relating to room temperatures; previously, these had meant dispatching staff to solve a variety of problems. Since the system was installed, the hotel has had virtually no complaints about rooms being too hot or too cold when people arrive or return after being out all day. Given that 60% of guests are repeat customers, and 70% of new guests come through recommendations from existing customers, an important strategic business consideration is ensuring that customers enjoy their stay; providing a high level of comfort in each room is a valuable step toward achieving this end.

The in-room sensors can also be used to alert hotels to unusual or fraudulent occupancy, as well as facilitate a quicker evacuation during an emergency or safety situation by identifying to fire marshalls, staff and hotel security personnel those rooms that are occupied.



STUDY CONFIRMS UNTAPPED HVAC SAVINGS CAN BE HARVESTED

The study confirmed that unoccupied hotel rooms and offices represent an unrealized opportunity to utilize programmable networked energy management software programs and occupancy sensors to reduce the energy consumption used for HVAC. These systems also deliver additional benefits in terms of hotel staff productivity and fire/emergency safety, and all without impacting occupant comfort.

Overall, the study found that the new EMS at the Holiday Inn North Vancouver reduced the hotel's annual energy consumption by more than one-quarter (28%) – a savings of $16,000 – over the previous twelve months. The analysis was adjusted to take into account variations in occupancy levels and temperature between the before-and-after energy consumption monitoring periods.

Furthermore, because the system helps to reduce the building's environmental impact, the hotel was qualified to receive rebates from the Canadian government (through Natural Resources Canada) for the installation's initial cost outlay. Overall, the analysis showed that the system paid for itself within 14 months and has already delivered an 83% return on investment.

ABOUT THE AUTHOR:

Steve Campbell, APR, BPE, MPE, is a writer and senior public relations consultant who writes for and about energy, lighting, construction and environmental companies, products and technologies.

SELECTING EFFECTIVE LIGHTING CONTROL

Allen-Bradley/Rockwell Automation

INTRODUCTION

In the past decade, there have been many improvements in the control of lighting for residential, commercial, institutional, and industrial facilities. This has resulted in more efficient use of electricity, greater utilization of daylight, and more versatile, automated, and convenient controls. Such control devices include contactors, relays, timers, sensors, operator interface graphic terminals, programmable controllers, and industrial computer-based control systems that may be utilized in diverse on-off and variable level control schemes. This article discusses different types of lighting controls and provides guidelines that may help in selecting the controls to suit individual needs, with particular emphasis on lighting contactors.

CATEGORIES OF LIGHTING CONTACTORS

In its simplest form, on-off lighting control can be a manually operated switch located on a wall, a timer, a relay mounted in a lighting fixture, separately mounted lighting contactors, or panelboards containing lighting contactors. Manually operated switches are often used in residential, commercial, and institutional facilities. However, the trend is toward the use of remote electrically-operated lighting contactors, programmable controllers, and wall-mounted operator interface graphic terminals (e.g., Allen-Bradley PanelView) to facilitate better energy management and supervisory control. To enhance ease of field conversions and servicing, many lighting contactors are designed to a modular platform with interchangeable contact blocks and coils.

Lighting contactors can be divided into three general categories: feeder disconnect type 2-, 3-, and 4-pole lighting contactors rated up to 2250 A to control large blocks of load, multi-pole lighting contactors with as many as 12 poles rated 20 A for multi-branch circuit control, and industrial relays rated 20…35 A with low voltage control for individual branch circuit or luminaire control. Lighting contactors are typically electrically held, mechanically held, or permanent magnet latch type, thus lending themselves to many forms of automatic control.

FEEDER DISCONNECT TYPE AND COMBINATION LIGHTING CONTACTORS

Feeder disconnect type lighting contactors are used for turning large blocks of lights on and off.

They are available in both NEMA and IEC type designs. Though available in sizes up to 2250 A, the more popular sizes range from 30…225 A because the trend has been to use them to control full-bus and split-bus lighting panelboards (See Figure 1).

Whenever lighting is being distributed over a wide area, two-pole, three-pole, and four-pole lighting contactors can help provide safety, economy, and convenience. Since small conductors can be used for control stations, and an almost unlimited number of stations can be used to control each lighting contactor, the electrical designer can be liberal with the number of multiple control stations used.

Shown in Figure 2 is a typical illustration of a three-wire control installation. In this instance, a three-pole Lighting Contactor is being controlled from three (3) remotely located (three-position, momentary center off) control stations. Typically applied for switching large blocks of lights at the panelboard, these types of lighting contactors can have ratings from 30…225 A.

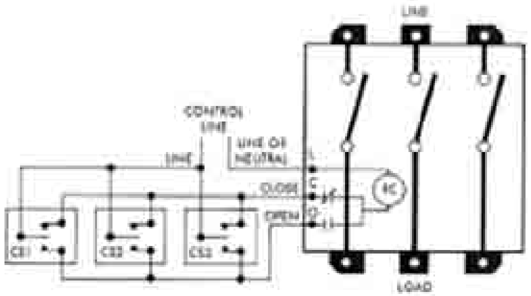


Figure 2. Typical Illustration of a three-wire control installation

Typical of the previous installation in Figure 2, feeder disconnect type lighting contactors might be a large high-rise office building. As an example, four 225 A lighting contactors could provide on-off switching of the four zones of lighting on each floor of a high-rise building. The lighting contactors could, in turn, be controlled by one or more master controllers. Feeder disconnect type lighting contactors can be provided as open type or enclosed.

Combination lighting contactors are available for applications that require combining switching and overcurrent protection in the same enclosure. Combination lighting contactors may be applied for industrial, highway and area lighting applications or where a lighting circuit may have to be disconnected for periodic maintenance (See Figure 3).

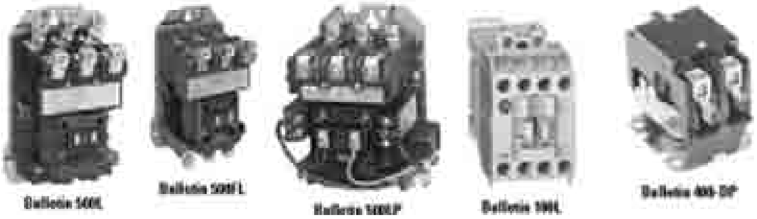


Figure 1. Allen-Bradley Bulletin 500L (10…2250 A top wiring electrically-held), 500FL (20…300 A feed-through wiring electrically-held), 500LP (20…300 A top wiring permanent magnet latching), 100L IEC Lighting Contactor, and 400 Definite Purpose Contactor

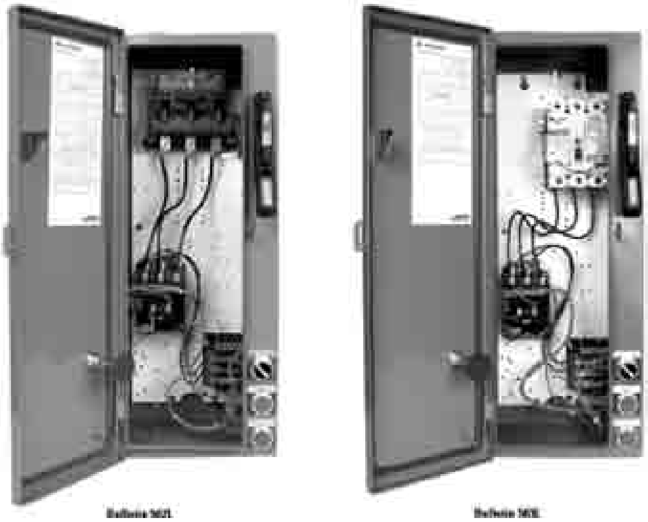


Figure 3. Allen-Bradley Bulletin 502L (with fusible disconnect) & 503L (with circuit breaker) Combination Lighting Contactors

MULTI-POLE LIGHTING CONTACTORS FOR BRANCH CIRCUITS

Today's compact, multi-pole, lighting contactors are available up to 12 poles, with contacts rated at 20 A for branch circuits (See Figure 4).

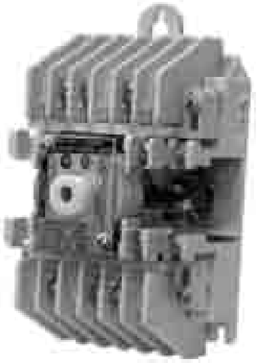


Figure 4. Allen-Bradley Bulletin 500LC Lighting Contactor

The compact multi-pole 20 A lighting contactors are usually mechanically held so they require only a momentarily applied current to either close or open. This enables the lighting contactor to be controlled by:

1. Manually operated, three-position, momentary contact switches with the center off positions.
2. Auxiliary relays or solid-state modules that operate as a function of photoelectric and occupancy sensors.
3. Timers with a single-pole, double-throw contact. Single-throw contacts can be utilized if a two-wire control module is furnished.
4. Energy management systems.

Being mechanically held, lighting contactors do not change position and disconnect the lights during a momentary drop, sustained reduction or complete loss of control voltage. Such contactors are not dependent on a continuous control voltage to maintain their position.

Because the operating coil is not continuously energized, coil hum and continuous coil power consumption are eliminated, thus avoiding irritating background noise and saving energy at the same time. Mechanically held contactor designs are often preferred when application involves UL 67 listed panelboards because the mechanically held contacts can better withstand fault currents.

From an energy conservation point-of-view, controlling a specific number of branch circuits or luminaires (2…12) rather than large blocks of lighting allows more design flexibility and customizing for the application. The latest multi-pole lighting contactors are available with optional solid-state control modules that provide convenient interfacing with various control systems. These will be discussed later.

Today's multi-pole lighting contactors are of shallow construction to accommodate mounting in panelboards or separate mounting in 4-inch stud-construction walls. Being mechanically held, they can be designed to withstand fault currents up to 22,000 A, symmetrical rms.

Magnetically-held, 20 A, multi-pole, lighting contactors are also used for lighting control.

To provide fail-safe lighting in the event of loss of control power, Form C relays with normally closed contacts that carry the lighting load can be used. However, contact configuration and reduced contact pressure of normally closed contacts often limit the ability to carry fault currents or meet UL requirements.

Multi-pole, double-throw, lighting contactors are also available. These can be used to select either of two lighting levels, e.g., day lighting or night lighting, from a common power source.

LOW VOLTAGE RELAYS FOR SELECTIVE LIGHTING CONTROL

Low voltage relays are usually single pole and used for individual branch circuit or luminaire control. These single-pole low voltage relays are available with contacts rated for 20 A at 120 and 277V AC. They are typically mechanically latched, requiring only a momentary 24V rectified AC switch circuit pulse to either open or close the load contacts. However, it should be noted that an open or failed unlatch control circuit will fail to unlatch the relay. For this reason, a mechanical latch unit should not be used where protection is needed against automatic restart after a power failure or where reliability to a control function is critical to safety.

There are also low voltage industrial relays (containing no mechanical latch) available. These 1-…12-pole low voltage industrial relays are available with contacts rated for 20…35 A for tungsten lamp loads to 480V AC. These industrial relays are modular and generally contain contacts that can easily be replaced or converted from normally open to normally closed (and vice versa) in the field (Figure 5).

A step-down transformer is required to provide low voltage control power for relay actuation.

One transformer can typically supply power for up to 15 relays, provided properly sized wiring is used. Low voltage control wiring must be segregated from other lighting circuit conductors (Figure 5).

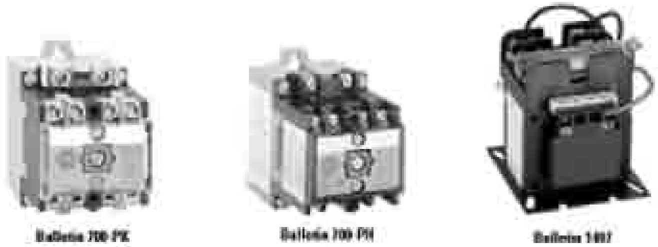


Figure 5. Allen-Bradley Bulletin 700-PK Relay, 700-PH Relay, and 1497 Control Transformer

Low-voltage relays are most often used in installations where a very high degree of selective lighting control is desired, as they can control individual lighting fixtures.

APPLICATION CONSIDERATIONS FOR UL 67 LISTED PANELBOARDS AND UL 508

Many mechanically held lighting contactors (e.g. Allen-Bradley Bulletin 500LC Lighting Contactor) have only one operating coil that is momentarily energized to either close or open the contactor.

When applying a lighting contactor to a UL 67 listed panelboard, the mechanically held type has certain advantages. The fact that the mechanically held version can be supplied with a single pulse-operated coil assures greater contact pressure, essential for withstanding short circuit fault currents. For example, a typical mechanically held, 20 A lighting contactor can withstand an available 22,000 A fault current when used with a 30 A molded case circuit breaker. Thus, they are satisfactory for use with UL 67 listed panelboards.

In addition to withstand current rating, consideration should be given to the type of lighting load. UL lists lighting contactors for general use loads, ballast (fluorescent) loads and tungsten (incandescent) loads. UL 508 requirements for ballast loads are more stringent than those for a general-use load, because UL requires ballast testing at a lower power factor and twice the nominal current rating. The requirements for a tungsten load are more stringent because they have to be tested for high inrush currents. A UL listed lighting contactor suitable for all three classes of load will have its nameplate so marked. The number of poles required for single-phase and three-phase applications also have a bearing on the continuous duty rating. Typical ratings for a small AC lighting contactor are shown for the Allen-Bradley Bulletin 500LC Lighting Contactor in Tables 1 and 2.

Table 1 Continuous Duty Rating

Load Type	Amperes Continuous	Pole to Load	
		1 for 1ø	2 for 1ø 3 for 3ø
Tungsten	20	250V AC	250V AC
Ballast	20	277V AC	480V AC
General	30	347V AC	600V AC

Table 2 Available Symmetrical Amperes RMS

Service Voltage	When Used with Molded Case Circuit Breakers	
	Withstand Current Rating (Amps)	Max. Breaker Size (Amps)
250V AC	22,000	30
480V AC	14,000	
600V AC	10,000	

The Allen-Bradley Bulletin 500LC Lighting Contactor is suited for UL 67 listed panelboards; however, it should be noted that many motor starter contactors, general-purpose relays, electrically operated circuit breakers, and some lighting contactors are not suited for UL 67 listed panelboards. Also they are not usually rated as per above nor listed per UL 508 requirements. Furthermore, use of a circuit breaker with trip elements for repetitive switching can alter the breaker's ability as an overcurrent protective device.

Manufacturers' catalogs and technical literature should be consulted to ensure that the equipment is properly rated for the application.

UL 508 REQUIRES:

Tungsten Loads

Endurance: 6,000 cycles of operation at rated current (20 A), 250V AC at a duty cycle of one second on, 59 seconds off. This duty cycle allows enough off time for the tungsten filament to cool so that the next time it is energized, the switch must close on approximately 20 times rated current for up to 14 cycles which is characteristic of tungsten loads. This duty cycle assures the worst test conditions.

Overload: 50 cycles of operation at 1.5 times rated current (30 A), 0.75…0.80 power factor, 600V AC.

Ballast (electric discharge lamps)

Endurance: 6,000 cycles of operation at two times rated current (40 A), 0.4…0.5 power factor, 480V AC.

Overload: 50 cycles of operation at three times rated current (60 A), 0.4…0.5 power factor, 480V AC.

General Use

Endurance: 6,000 cycles of operation at rated current (20 A), 0.75…0.80 power factor, 600V AC.

Overload: 50 cycles of operation at 1.5 times rated current (30 A), 0.75…0.80 power 28 factor, 600V AC.

Power Factor Corrected Ballast

The Allen-Bradley Bulletin 500LC Lighting Contactor is suitable for power factor corrected ballast far in excess of 6,000 cycles of operation.

Important: UL does not test for this requirement. However, we believe that this additional endurance test is a valuable, and unique feature that illustrates the lighting contactors high reliability.

LIGHTING CONTROL METHODS AND SENSORS

CONTROL MODULES

The versatility of controlling lighting contactors is illustrated by the availability of optimal control accessories that can be provided to interface with various control schemes such as energy management systems, microprocessors, photoelectric cells and timers. These accessories may be in the form of discrete auxiliary relays or combined with solid-state modules, with the trend towards the latter. Three control methods are two-wire control, three-wire control, and start-stop control.

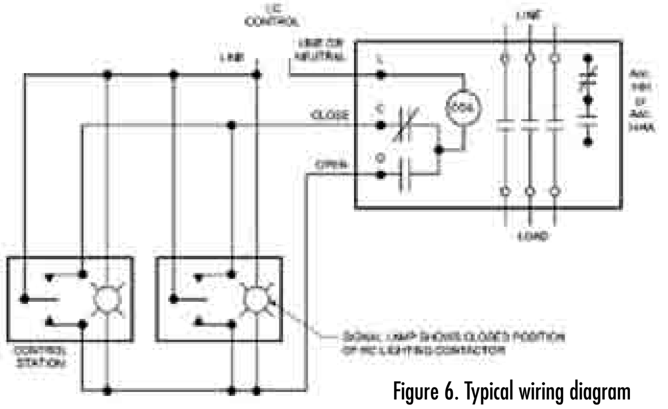


Figure 6. Typical wiring diagram

Figure 6 shows a typical wiring diagram of a 20 A multi-pole lighting contactor being controlled from two (2) remotely located (three-position, momentary, center off) control stations. The control stations in this figure are shown with signal lamps to indicate open or closed status of the lighting contactors' main contacts. Lighting contactors of this type typically can control from two to twelve 20 A branch lighting circuits.

TWO-WIRE CONTROL

If the lighting contactor is being operated from a programmable source, logic controller, or any control device providing control voltage to the lighting contactor by closing a set of single-pole maintained contacts, it would be necessary to provide an intermediate control device or a two-wire control module. Solid-state control modules provide control voltage to the contactor by responding to the opening and the closing single-pole single-throw (SPST) maintained output contacts in the primary control device. Therefore, different control voltages can be applied to operate the lighting contactor (i.e., 12V AC/DC, 24V AC/DC, 120V AC, 240V AC, 277 V AC).

When utilizing a mechanically held design (e.g., the Allen-Bradley 500LC Lighting Contactor), such lighting contactors only require a momentary pulse of current to operate, the maintained current from the primary control device is converted to a momentary on/off pulse to the coil.

Therefore, the coil only experiences a momentary pulse of current to open and close the lighting contactor's main contacts (Figure 7).

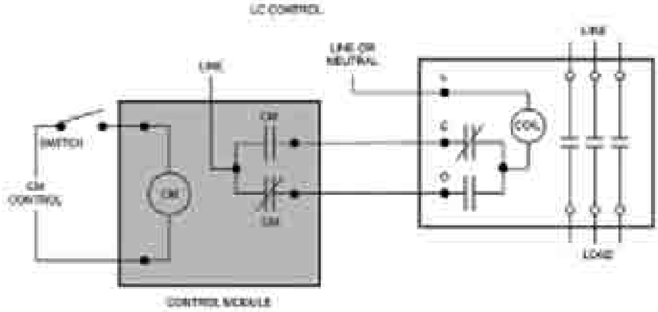


Figure 7. Two-Wire Control

THREE-WIRE CONTROL

The three-wire control method permits extended control line runs. It provides three-wire control of the lighting contactor whereby one circuit is energized to close the lighting contactor and another is energized to open the lighting contactor. If neither or both circuits are energized, no operation will occur. Therefore, a single-pole, three-positioned (maintained off-momentary on position) type control station as shown in Figure 7, or two interlocked normally open push buttons, can be used with the accessory to operate the contactor. See Figure 8.

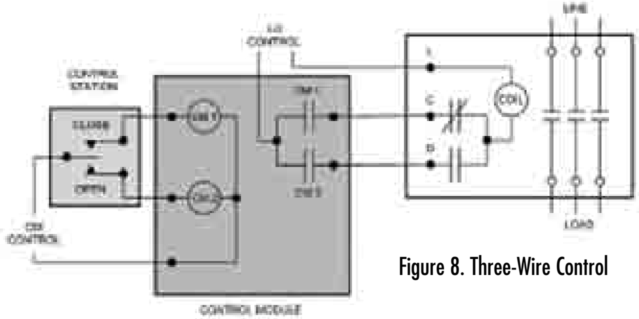


Figure 8. Three-Wire Control

START-STOP CONTROL

This control method provides start-stop (on/off) control of the lighting contactor. The accessory is energized to close the lighting contactor and de-energized to open the lighting contactor. Therefore, one normally closed and one normally open control station can be used with the accessory to operate the lighting contactor (Figure 9).

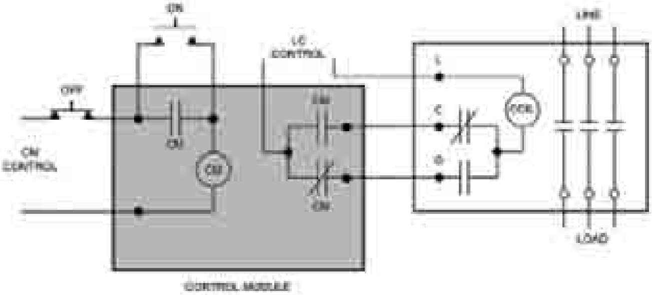


Figure 9. Stop-Start Control

Optional control accessories can be applied at various control voltages such as 24V DC, 24V AC, 120V AC, and 277V AC. The solid-state versions are compact and can often be mounted directly on the contactor. Their power consumption is extremely low (less than 1.0 VA), thereby making them particularly suitable for energy management systems and long control wire runs (Figure 10).

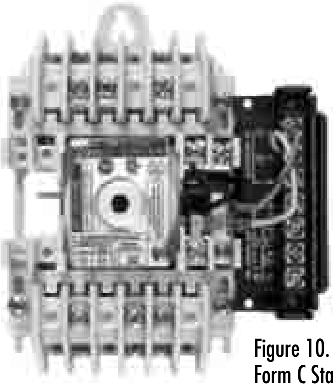


Figure 10. Bulletin 500LC Lighting Contactor with Form C Start-Stop Control Module

CONTROL LINE RUNS

Consideration should be given to control line runs when selecting lighting contactors and to the size of control wire between the lighting contactor and control station. The longer the line run, the larger the required wire size. Manufacturers provide line run data for lighting contactors using various wire sizes. When more than one lighting contactor is connected to the same control conductors, the data can be used in terms of "contactor feet". The allowable run for a group of lighting contactors is equal to the listed values divided by the number of lighting contactors. For example, if one lighting contactor has an allowable run of 1000 feet with #12 wire, 4 lighting contactors will be limited to 250 feet if they are operated simultaneously.

Auxiliary relays and solid-state modules, as previously discussed, are often used where long control runs are required and it is desirable to limit the wire size.

TIMING CONTROLS

A broad variety of time controls are available for direct control of lights or control of lighting contactors. They include 24-hour, 7-day calendar and astronomical dial timers.

Though motor-operated timers are economical and quite suitable for many applications, the trend is toward electronic timers. Modern electronic timers use microprocessor technology and are extremely versatile and multi-functional in controlling many lighting areas. In the event of a power outage, electric timers can stagger the restoration of lighting loads to limit power surges. Internal batteries assure that the timers will retain their memory and keep timing during power outages (Figure 11).

Figure 11. Allen-Bradley Bulletin 1760 Pico™ Controller, 700-HR52, 700-HRM, 700-FS, 700-HNK, 700-HRF, 700-HX, 700-HNC, 700-HXM

Electronic timers are used where multiple circuits, accuracy, and more sophisticated programming are required. They can be scheduled years in advance, taking into account holidays, etc., and allowing for leap years and daylight savings time changes. However, some have a limited load-carrying capacity and may require interfacing when used with lighting contactors. As previously discussed, optional solid-state control modules are available for such interfacing.

Photo-timers combine remotely mounted photoelectric switches with a 7-day timer. They can control multiple circuits, each with its own program. For example, one circuit can provide on and off by photoelectric control; a second, on by photoelectric control and off by timer; and the third, both on and off by timer. Manual bypass can maintain any circuit on or off for prolonged period without affecting the other circuits or the timer settings.

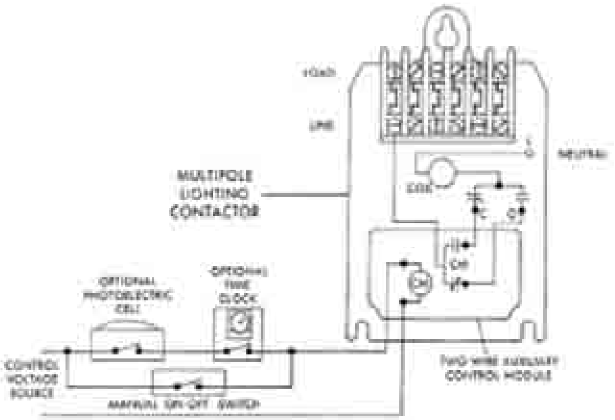

LOAD
LINE
NEUTRAL
COIL
MULTIPOLE LIGHTING CONTACTOR
OPTIONAL PHOTOELECTRIC CELL
OPTIONAL TIME CLOCK
CONTROL VOLTAGE SOURCE
MANUAL ON-OFF SWITCH
TWO-WIRE AUXILIARY CONTROL MODULE

Figure 12. Photoelectric sensor with timer

SENSORS

Sensors for lighting controls are either photoelectric sensing or presence detectors. Photoelectric sensors are normally set to switch lighting on at dusk and off at dawn. Adjustments can be made to change response to higher or lower levels. Built-in time delay helps to eliminate nuisance switching in response to sources other than natural ambient light, or passing shadows.

Photoelectric sensors are often combined with timers to provide a more efficient light control.

Figure 12 shows such a control arrangement. Contacts on both photoelectric switch and the timer must close to cause the multi-pole lighting contactor to switch on the lights. Opening either set of contacts will open the lighting contactor, thus turning off the lights. A typical application would be an industrial parking lot where lighting is required only Monday through Friday evenings, and is turned on at dusk and shut off at midnight. The two-wire control may be a separate electromagnetic control relay or a built-in control module as shown.

A variety of presence detectors or occupancy sensors have been recently developed. These detectors automatically activate the lighting controls. They are designed to turn lights on upon sensing heat or motion caused by human occupancy within a defined space and turn them off at some preset time after the last person leaves.

Bulletin 500LC Lighting Contactors and Control Modules have matched performance characteristics. It is always preferred to use Allen-Bradley control modules due to the possibility that marginal specifications of substituted devices (relays) may yield less than desirable switching action. Poor switching action of such marginal interposing relays can compromise the performance of the lighting contactor.

INDUSTRIAL COMPUTER/PROGRAMMABLE CONTROLLER BASED CONTROL SYSTEMS

Today's industrial computer and programmable controller (PLC) based control systems are sophisticated versions of electronic timers. The heart of such a system is an industrial computer and/or PLC-based controller that hold(s) in memory a series of on-off instructions to the lighting circuits throughout a building. They can provide minute-by-minute control of an entire lighting scheme according to a user-determined schedule, with pulse initiation of the control signal generated from its internal clock. Photo, occupancy sensor, and manual controls are often utilized as logic inputs in determining the control decision.

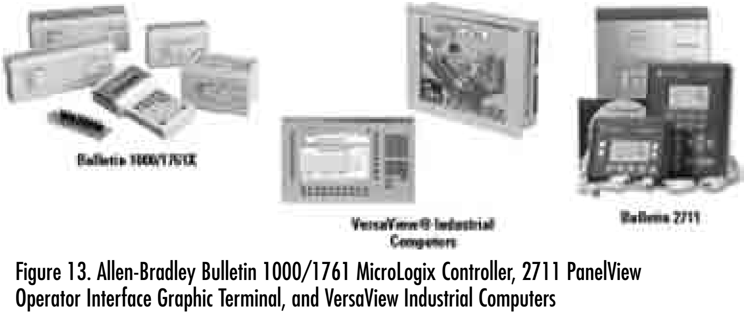


Figure 13. Allen-Bradley Bulletin 1000/1761 MicroLogix Controller, 2711 PanelView Operator Interface Graphic Terminal, and VersaView Industrial Computers

Multiplex signals from the control system can be sent throughout the building via a twisted pair of communications type wire. With other arrangements, signals can be sent via existing power wiring to the receiver control modules. Because no copper-to-copper connection exists between the primary and secondary of a conventional power transformer, couplers are available when command signals must bypass a transformer.

The codes from the controller are transmitted to the transceivers where they may be combined with other signals and, in turn, transmitted to the lighting contactors with control modules that require only a momentary electrical pulse to operate. The lighting contactors are often fitted with low voltage control modules that can operate directly from the controller output.

Programming discretionary control and over-ride functions can be displayed on a CRT or operator interface graphic display and recorded on a hard copy printer. Figure 14 shows a conceptual scheme for an industrial computer/PLC-based lighting control system.

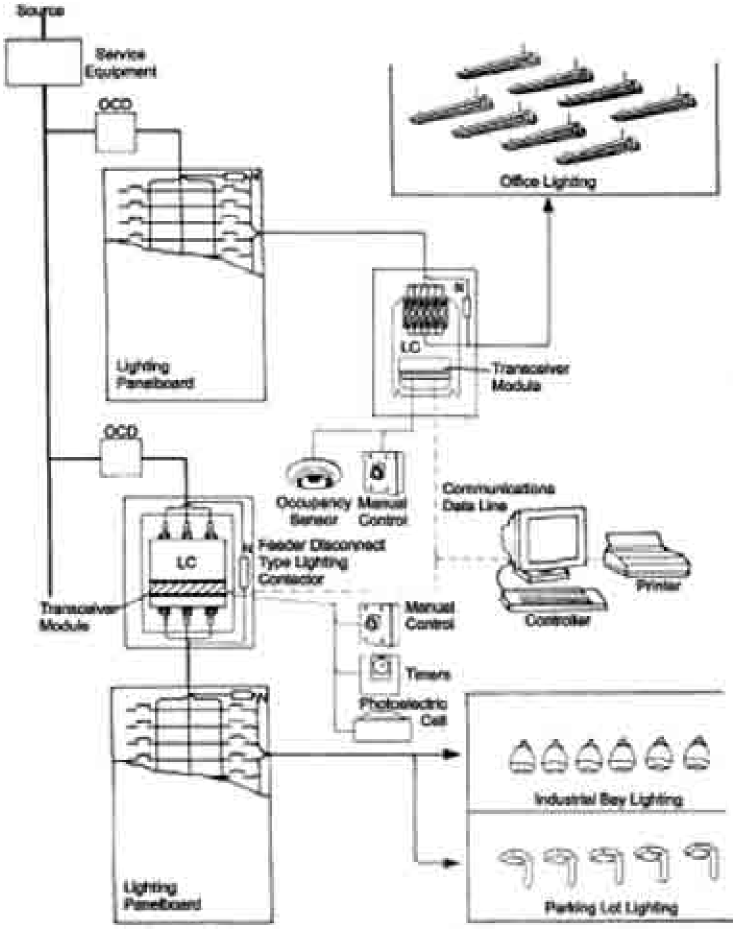


Figure 14. Conceptual Lighting Control System

LEVEL CONTROLS

In some energy management applications, it is desirable to provide a variable level of electronic illumination. Dimmers are the most often used means for providing lighting level control. Today's solid-state dimmers are suitable for incandescent, fluorescent, and HID lighting. Through the use of intermediate controllers, dimmers can operate as a function of available day lighting.

To fully exploit daylight as a source of illumination, it is necessary to establish an interactive link between ambient daylight conditions and the artificial lighting system. This can be achieved with a photoelectrically controlled lighting system that adjusts the output of the artificial lighting system based on the amount of prevailing daylight. Lighting control hardware that links artificial lighting to available daylight generally falls into two categories:

1. A continuously dimmable artificial lighting system that is controlled by photosensors that continually adjust the artificial lighting level in response to the amount of daylight striking the control photosensors. At the heart of the system is the controllable output ballast or dimming ballast.

2. A photo relay-based system that automatically switches off perimeter lighting when day lighting is sufficient to meet lighting needs.

The artificial lighting in daylight zones is used as fill-in lighting to provide even illumination across the occupied space. The amount of usable daylight is dependent on the window and skylight types and sizes, window and skylight treatments (drapes, glazing, etc.), building orientation and design, interior design, and furnishings.

SELECTION GUIDELINES

There is no set of specific rules that conveniently lead one to select lighting controls. However, the following factors will have a bearing and can serve as a general guide.

A large facility may economically justify a building management system or programmable controller that provides centralized lighting control. On the other hand, a small facility may obtain optimum savings by selection of a simple timer control.

SIZE OF INDIVIDUAL LIGHTING AREA

If the current drawn by an individual lighting unit exceeds 20 A, feeder disconnect type or combination lighting contactors may be the choice. Small areas such as individual offices would be candidates for low voltage relays for selective lighting control or multi-pole lighting contactors for branch circuits. In either case, these devices normally would be controlled by manual switches, operator interface graphic terminals, timers, photoelectric, and occupancy sensors, etc.

FACILITY USE

If the facility provides commercial rental of office space, flexibility may be a desirable design consideration. In other cases such as industrial and institutional facilities where lighting requirements are more fixed, multi-pole, and higher ampacity mechanically held, electrically held, or magnetic latch feeder disconnect type or combination lighting contactors may be the preferred choice.

EXISTING FACILITIES

Older buildings can often be upgraded using multi-pole lighting contactors. They can be mounted adjacent to the existing lighting panelboard to control only those circuits serving selected lighting loads. Extensive rewiring to existing fixtures may be avoided. Multi-pole lighting contactors used with occupancy sensors can be used to sectionalize a facility into functional work areas. This can help yield significant energy savings and possibly a short payback period.

CONCLUSION

Recent technological advances have made available a wide choice of switching equipment and control systems for lighting. This presents opportunities to lighting designers to provide quality lighting. Regardless of the type and size of the facility a designer may deal with, there are suitable types of controls to use. Sound judgment in the selection of control schemes and equipment can achieve a quality lighting system with optimum energy savings.

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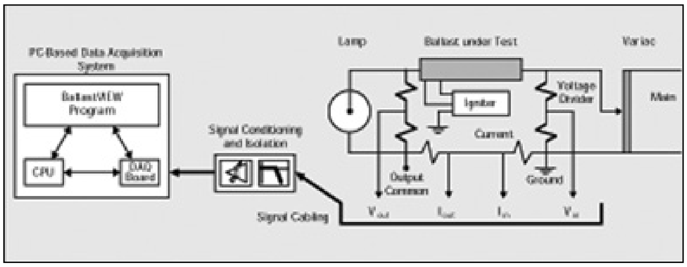
TESTING ELECTRIC STREETLIGHT COMPONENTS WITH LABVIEW-CONTROLLED VIRTUAL INSTRUMENTATION

Ahmad Sultan, Computer Solutions, Inc.



Hardware Block Diagram of the Ballast Laboratory

INTRODUCTION

Our task was to develop an automated test system for magnetic ballasts used in high-pressure sodium (HPS) streetlights.

Our client, who manufactures ballasts for the North American and international markets, believes that product development and quality assurance require thorough and complete testing of prototypes and production samples to verify compliance with national and/or international standards.

The test system needed to accommodate the following:

- Different types of core and coil ballasts, such as reactor, autotransformer, constant wattage autotransformer (CWA), and constant wattage isolated transformer (CWI)
- Operating voltages from 120 to 600 V and rated lamp wattage from 50 to 400 W
- Capacitors for wattage control and/or power factor correction
- Different lamp igniters
- Open-circuit, short-circuit, lamp-starting, and lamp running tests

At the ballast input and output ports, we needed to measure true rms values of current and voltage, true power, and the ratio of watts to volt-amperes (power factor, if the voltage and current waveforms are clean sinusoids). Because HPS lamps are nonlinear loads, we monitor current and voltage peak values and crest factors, along with total harmonic distortion.

SYSTEM INTEGRATION APPROACH

With the tight budget of a growing company, establishing a test bench with the functionality we required using conventional test equipment becomes difficult. We implemented a virtual instrumentation approach to achieve project objectives within budget while maintaining flexibility for future needs.

Virtual instrumentation consists of using mainstream computers, off-the-shelf plug-in instrumentation boards, and software. Because the virtual instruments you create with these products are user-defined, not vendor-defined, you can tailor applications to meet your needs exactly. Some of the benefits of virtual instrumentation are ease of use, flexibility, and savings of time and money.

We used LabVIEW software as the heart of the instrumentation system. BallastVIEW is the name of the LabVIEW application we wrote to acquire signals, process data, and present results to the user on the computer screen.

The instrumentation system hardware consists of:

- 486 DX2-66 PC (12 MB RAM, 340 MB hard drive) running Windows
- Variac (manually adjustable transformer) supplying AC power to the ballast under test through the system test fixture
- System test fixture containing switches and wiring required for the different test configurations
- Transducers for sensing current and voltage signals (such as resistive dividers and current shunts)
- Anti-aliasing RC filters, with components selected to avoid loading the board input amplifiers
- 5B signal conditioning modules, to amplify and isolate the filtered signals
- National Instruments Lab-PC+, installed in the PC, to digitize the conditioned signals

The cut-off frequency of the anti-aliasing filters was set to half the sampling frequency; the RC filters also serve to protect the electronics items from the high-voltage spikes generated when the igniter starts the lamp.

We configured the Lab-PC+ board for bipolar differential input (four channels).We set the sampling frequency to 7680 Hz/channel. Acquisition was software-triggered on the rising slope of the input voltage.

BALLASTVIEW PRESENTATION

The LabVIEW screen on the next page is the front panel of BallastVIEW. It illustrates a stack of VIs representing an input AC power analyzer, an output AC power analyzer, a waveform graph, and a harmonic analyzer. The controls at the top of the screen are switches for controlling acquisition, metering, harmonic analysis, and program execution. The user can capture a single shot or continuously acquire signals.

For the power analyzers, the indicators (from left to right in each row) display the rms, maximum, minimum, peak average, and crest factor of each signal. The active and apparent power, and their ratios, is displayed in the right column.

The waveform graph displays the signals acquired by the data acquisition (DAQ) board. Because both voltage and current waveforms are displayed, the ordinate is labeled in relative units (PU).

To find the true amplitude of a particular signal, multiply its measured value from the graph, in PU, by the respective base value from the PU Base table (to the right of the waveform).

The line spectrum, shown in the bottom right corner, displays harmonic magnitude in either peak volts/amperes or per unit values normalized to the fundamental component of the respective signal. Magnitude of harmonics can be checked by flipping the cursors of the harmonic magnitude indicator (bottom center). The user can utilize window signals before applying the Fast Fourier Transform.

EXAMPLE RESULTS

The results presented in the BallastVIEW screen are test results for a 200 W CWI ballast. The output power analyzer indicates that the lamp is operating at rated lamp power. Lamp voltage and current are very close to the ANSI reference specifications (100 V and 2.4 A).

Lamp current crest factor (CCF) is 1.6 (1.8 is the maximum permissible).

The input power analyzer indicates that the ballast draws 2.037 A at rated input voltage. Ballast loss is approximately 39 W and the power factor is high (0.973 lagging).

The waveform graph shows almost clean input voltage and current signals.

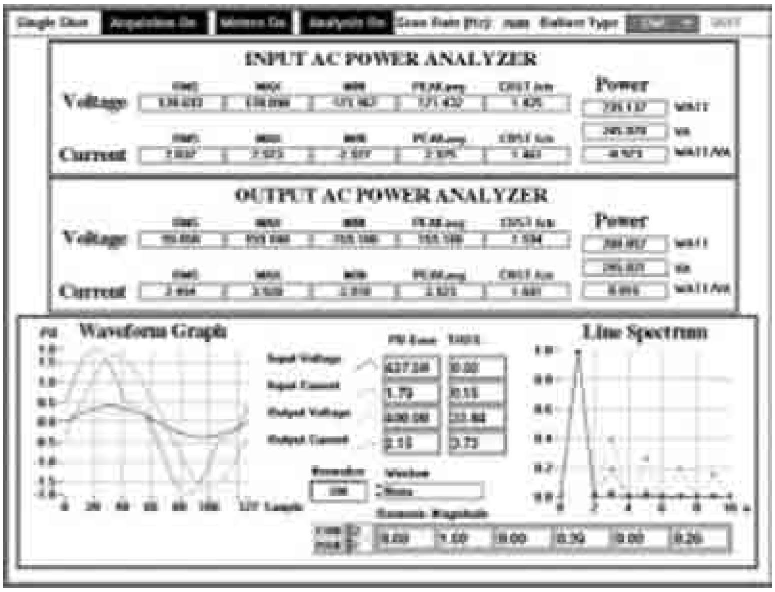
Output (lamp) voltage is the square waveform of a typical arc in a high intensity-discharge (HID) lamp, containing the full odd harmonics spectrum. The magnitude of the lamp voltage third-harmonic component is 39 percent of the fundamental. Total harmonic distortion (THD) of lamp voltage and lamp current are 33.84 percent and 3.73 percent, respectively.

We verified the credibility of this system by obtaining agreement with test results from an independent test laboratory, electric utility companies, and customers of the ballast company.

CONCLUSION

BallastVIEW measures and displays the electrical parameters required to test and develop ballasts and performs on-line waveform analysis. The result is a flexible, high-performance, easy-to-use, and cost-effective PC-based measurement system, which saved time in both product development and production testing.

An advantage of using LabVIEW is our ability to increase BallastVIEW functionality in the future, for example, by monitoring the ballast-lamp characteristic curves and compiling results. The core of the BallastVIEW program constitutes the cornerstone for testing other electrical products, such as transformers, rectifiers, inverters, and UPSs, as well as for power line monitoring.



LabVIEW Front Panel showing BallastVIEW Test Results

LIGHTING CONTROL SAVES COCA-COLA

Amatil Energy

Australia's market leader in the manufacture and distribution of soft drinks, Coca-Cola Amatil has six bottling plants and a PET (PolyEthylene Terephtalate) reformation plant in Sydney, as well as PET bottle manufacturing facilities in all states.

Lighting represents a significant cost at all Coca-Cola Amatil sites, accounting for about 15 to 20 per cent of total electricity.

"Introducing new lighting management systems has delivered us substantial energy savings at each of our plants," says Colin Hastwell, Coca-Cola Amatil's senior project engineer.

"Most importantly, we were able to integrate the new lighting controls with our different plants' needs, ensuring that we could achieve optimum performance."

THE LIGHTING CHALLENGE

Originally, Coca-Cola Amatil's factory and warehouse lighting was a "one on, all on" system. To develop the company's Cooperative Agreement, each site developed an individual action plan and lighting projects became a significant area for action.

The sites investigated a range of energy saving opportunities, such as dimming systems, switching systems and the installation of more efficient lamps. Ultimately, the sites made decisions based on their specific requirements for production scheduling, delivery times, skylighting and ambient conditions.

Coca-Cola Amatil's soft drink bottling plant at Kewdale in Western Australia assessed several lighting management systems and chose the Clipsal C-Bus system as the most suitable for its conditions.

The C-Bus system had been installed in many similar industrial environments, and appeared to offer greater potential to expand without requiring substantial extra controlling hardware.

A key concern in the investigation and selection process was the impact the system would have on other equipment warranties. As the C-Bus system did not affect lamp or switch-gear life, it was found not to have a major impact.

Apart from Kewdale, Coca-Cola Amatil has implemented major lighting projects at Richlands in Queensland, Moorabbin in Victoria and Smithfield in NSW. Implementation is planned for Thebarton in South Australia later this year.

Each manufacturing plant undertook similar site-based investigations in developing their action plans, and inspected the Kewdale installation before concluding they would also use the Clipsal system.

INDIVIDUAL CONTROL

The Clipsal C-Bus is a switching system that individually controls each lamp. Every lamp is fitted with a small electronic relay unit and uniquely identified with an individual and group address. These relays are linked with Cat 5 networking cable, so that communications are separate from mains power.

Lamp characteristics are managed via a personal computer remote from the actual fitting. Profiles can be built for each lamp group so that they correspond directly with the requirements of each production line or work area.

UNIQUE SET-UP

The set-up at each site has several unique characteristics.

At Kewdale, the C-Bus system monitors daylight levels in three locations and enables the continuous dimming of lamps.

The system also allows for further control over lamps that dim or switch frequently due to intermittently changing ambient conditions. To preserve lamp life, a maximum of four changes in light level or switching is allowed in one hour before full lamp output is restored for an extended period.

At Richlands, groups of lamps are controlled to switch off at the end of production. However, if maintenance crews need access to certain areas, they can program for that area to switch on for a single shift, after which all lamps automatically switch off.

At Moorabbin, installation of the C-Bus system followed a global lamp replacement in 1998. As part of this upgrade, skylights were installed across 15 per cent of the roof, allowing for daylight control in addition to switching capability.

At Smithfield, the C-Bus system is currently being installed in the main manufacturing plant where a new lighting installation has recently been completed in the warehouse. The lighting is controlled via several daylight sensors.

The C-Bus system at Kewdale was initially installed with micro-processor controllers providing the controlling 'smarts' of the system. These proved to be inadequate for some of the complex processing required to ensure optimum operation.

A new software controller by Citect was installed – the first example worldwide of such a system – and this has proven to be a successful method of addressing the problem. In addition, a simple and flexible system of programming was written using Citect's programming language, ci-code, as the base code. The Citect controller will now be installed progressively at other sites.

GREENHOUSE RESULTS

Coca-Cola Amatil is expecting to reduce greenhouse emissions at all sites by more than 2,000 tonnes of CO2 per year, or 1.35 per cent of emissions generated from bottling and beverage packaging.

The company is also achieving cost savings from the C-Bus system.

"Our lighting electricity consumption has dropped by 30 to 40 per cent at all our sites," says Mr Hastwell. "We're now saving between $30,000 to $50,000 per annum at some sites, including our beverage packaging plants."

As the initial cost of the hardware and software ranged between $110,000 to $130,000 for all sites, Coca-Cola Amatil is expecting to recoup its investment within two-and-a-half to four years.

AN ANALYSIS OF THE COST OF LIGHT FOR SOLID STATE LIGHTING

Kevin Dowling, Color Kinetics Inc.

1. BACKGROUND

LEDs, the key component in solid-state lighting systems, have increased in performance and decreased in price for several decades. As a result of this improvement, LEDs have successfully penetrated a variety of markets including signage, automotive, personal lighting and transportation. To date, these markets are primarily colored light sources but white LEDs are also on a rapid and inexorable march towards other applications, including general illumination.

The crossover point when the initial cost of an solid-state lighting system is equal to or less than a traditional lighting system has been cited as the 'holy grail' by many in the lighting industry. Some identify this confluence as the point at which solid-state lighting is finally viable for general illumination. This is short-sighted because the initial cost of a system is but one element of the cost of light. The true Cost of Light incorporates lifetime and operations costs as well as the initial cost. By this measure, as we will show, LED-based illumination is becoming economically viable for many applications today.

2. PURPOSE

This is an exercise in prediction. Beginning several years ago with some back-of-the-envelope calculations, this ongoing analysis has been refined and improved to provide a succinct picture of emerging trends in the Cost of Light for both traditional light sources and solid-state light sources. This paper details the data gathering process and the assumptions in the Cost of Light estimates.

$$\frac{1}{lumens}\left[\left(\frac{lamp\_cost + labor\_cost}{lifetime}\right) + power * energy\_cost\right]$$

Equation 1: The Cost of Light formulation[1]

The Cost of Light formulation, shown in Equation 1, is an accepted industry definition of the operating or lifetime cost of a light source. It takes six criteria into account:

- energy costs
- power consumption
- labor costs
- lamp costs
- lifetime
- light output

The result is a metric whose dimensions are dollars per million-lumen-hours. This is similar to another common cost metric that people are familiar with: the cost of energy which is expressed in dollars per kilowatt-hour.

In this document data sources and assumptions are revealed and examined. A companion annotated spreadsheet model is used to store the data, perform the calculations and plot the results. Also, a substantive list and discussion of additional factors that could affect the Cost of Light, but are not incorporated into the formulation, are also presented. Three specific regions show the current Cost of Light for the dominant lighting technologies: incandescent, halogen and fluorescent. Forward-looking data points are based on industry projections of performance and pricing improvements in LED devices.

3. HISTORICAL PERFORMANCE AND PRICING TRENDS IN LIGHTING

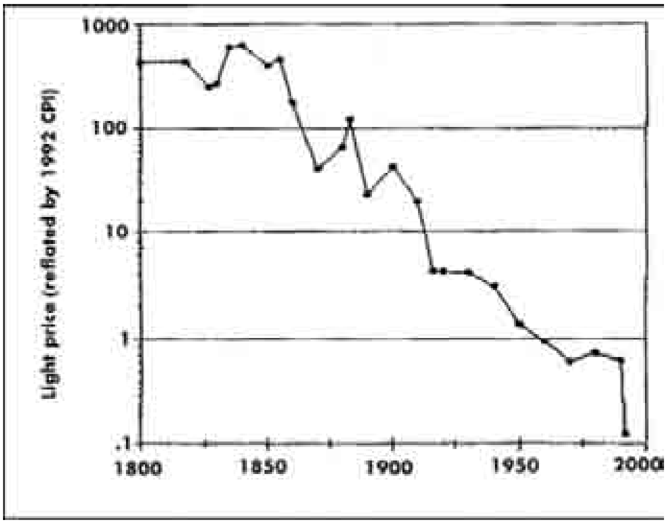


Figure 2. The cost of light as a service is shown in dollars per lumen for the last 200 years. (From Nordhaus)

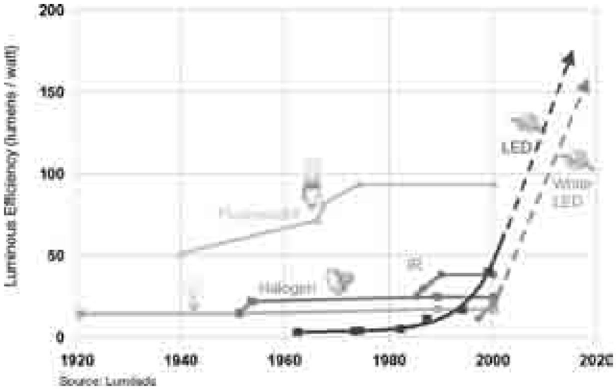
From Nordhaus' economic study of the cost of light as a service, this chart shows two centuries of lighting history and associated costs. Nordhaus used lighting as a case study to show that traditional measures of consumer prices do not reflect the true cost of services. The service was the amount of light delivered to the consumer and related that to real wages required to purchase an amount of light. Nordhaus represented the cost of light in dollars-per-lumen since he focused on the purchase of light (lumens) versus operational costs. His work accounted for several lighting technologies including wood, oil, candles, gas, and electricity. The overall trend is clear; a significant decrease in the upfront cost of light. The precipitous drop in the latter part of the 20th century is thought to be due to increasing competition, decreasing margins and the advent of mass merchandisers and big box retailers such as Wal-Mart, and DIY stores.

4. LED TRENDS – EFFICACY AND BUCKS FOR FLUX

Figure 2, adapted from Lumileds, illustrates the evolution of lighting technology efficacy over time. It shows the overall trends in traditional lighting technologies and the rapid progress and forecasted developments in LEDs. Note that the efficacy of extant technologies has leveled off. They are not improving in efficacy very much, if at all.

Theoretical limits for white LED efficacies are thought to be in the 200-220 lumens per watt range. Most importantly though, for this metric, is that the available headroom for conversion efficiencies is significant; upwards of 75% in large areas of the visible spectrum.

Even LED improvements will level off at some point but target efficiencies of between 150-200 lpw for white light sources are viewed as practical over the next ten years. This puts LED illumination on par with the most efficient light sources used today.



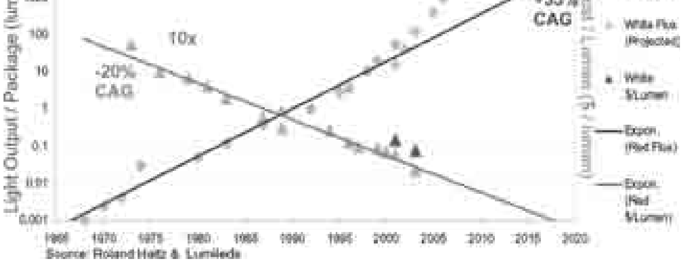
Source: Lumileds

Figure 3. The efficacy of most lighting technologies has leveled off while LEDs continue to improve.

In the next chart in Figure 4, a remarkable set of historical data is shown along with some projections. These are dramatic exponential improvements in LED performance and costs.

This chart has a semi-log scale on the Y-axis, which provides a straight line plotting of geometric or exponential change. Log scales are useful to show data over a very wide range, especially at small values. Also, importantly, a percentage difference is represented by the same linear displacement throughout a log plot.

Figure 4, also based on data from Agilent data, shows the improvements in both pricing and performance for LEDs over the past forty years. The chart illustrates red LED technology in particular but even more rapid progress has been made in other colors, including white over the past decade. The efficacy curves will begin to level off over the next several years and lamp or package outputs will be the important measure of performance. Continually increasing flux from a package argues for large LEDs but the point is that people will be buying flux per dollar, not necessarily efficiency.



Source: Roland Haitz & Lumileds

Figure 4. Improvements in LED output and pricing have been substantial over several decades.

In this chart the flux-per-package trendline shows a good fit to the data with an R2 fit of 0.9791 and illustrates the progress of LED flux outputs and pricing trends.

The performance improvement trend is equivalent to a compound annual growth rate (CAGR) of 35 percent. Based on the fit of the exponential equation, the per-decade improvement is 19.2 which is close to the 20x cited in the Lumileds data. Over several decades the difference between 20 and 19.2 will matter, but for a single decade, i.e. the next ten years, it is a reasonable value to track improvement.

In previous years, this same graph has depicted a 30x per decade improvement in flux per package. Lumileds has explained that they and Roland Haitz, a retired scientist who has been tracking this data while working with Hewlett-Packard, Agilent and Lumileds for many years, has re-plotted the data with an eye towards general industry data as well as being more conservative on the projections.

These trends are likely to continue as levels of investment in LEDs continue and grow.

Current laboratory research has revealed very promising results that will manifest itself in new generations of products over the coming years. These improvements are in a variety of areas including material compounds, dopants, geometries, processing tools and more.

4.1 INTERSECTION

A Department of Energy study from 2001 projected that LED lamp prices will drop from around 275 dollars per kilo-lumen ($/klm) in 2000 to below $50/klm in 2010.

However, volume pricing of high-flux-emitters mounted on PCBs are already priced in the range of $100-$200 per kilo-lumen today. If we look at price halving trends using the Agilent data then the LED pricing will be down 50% within 3 years. However, we need to consider a complete fixture in any comparison and not simply the LEDs, which will constitute a decreasing fraction of system costs.

Figures from the ADL study indicate that the white light market is increasing at the rate of 0.25 Tera-lumens per year. The replacement lumen market is about 33% per year including replacements (27%), new construction (1%) and retrofits (5%). The study estimates that only 1% of floorspace per decade undergoes lighting retrofits purely for energy savings.

5. THE TRUE COST OF LIGHT

An incandescent bulb may cost a quarter but will use more than ten times that in energy costs over its relatively short life. According to General Electric's Lighting group, the cost of the lamp can be as little as 4% of the total cost of light. For example, a 100W light bulb x 800 hour lifetime x $0.10/KWh energy costs = $8.00 in energy costs. That light bulb today costs about $0.24 and so the operating energy costs over the lifetime of the lamp are over 30 times greater than the initial cost of the lamp itself. The cost of this light bulb is nearly insignificant compared to the energy costs and, in commercial establishments; the replacement cost can be high as well.

So what is the real cost of light then? The Cost of Light includes the following:

- **Performance**. The light output in Lumens as specified by the manufacturer.
- **Cost**. The upfront cost in dollars. This is the full retail or list price of a lighting product.
- **Replacement cost**. The labor cost to replace a lamp in dollars.

- **Lifetime**. The useful life in thousands of hours.
- **Power**. Power consumption during operation. Measured in Watts.
- **Energy Costs**. Measured in dollars per kilowatt-hour. According to the DOE, the national average for residential use is $0.085. US residential electricity rates range from $0.05/kWh to $0.156/kWh. In general, electricity rates are divided into three major categories: residential, commercial and industrial. Over all sectors, rates were about $0.72/kWh in 2002. However, electricity prices in New York, California and New England are substantially higher. Examples include New York at 11.29 cent per kWhr, Massachusetts at 10.18 cents/kWhr to 12.5 The Cost of Light cents per kWhr in California. It is not clear whether the average US cost of electricity reflects an average of state figures or is population based.

5.1 ASSUMPTIONS

LED costs are based on list prices for a commercially available fixture. For other lighting sources, retail prices or lamps at high-volume mass merchandisers such as Home Depot and drug stores are used. All data on lifetime on light sources is directly from the manufacturer labels or from catalogs. All data for a particular technology such as incandescent or halogen were taken from a variety of products and the Cost of Light values were averaged to obtain a mean cost for that particular technology. To make the comparisons relevant, board-level LED products were used to compare to lamp sources.

The true cost of light can then be calculated as follows:

$$\frac{1}{lumens}\left[\left(\frac{lamp\_cost + labor\_cost}{lifetime}\right) + power * energy\_cost\right]$$

This equation allows us to use projections of LED trends and present and future cost comparisons between traditional lighting technologies and then the cross-over points when solid state lighting technologies become cost competitive with existing lighting technologies. Note that this particular form does not incorporate the time value of money which would further benefit the comparison to LEDs.

The dimension of this equation is in dollars per million lumen hours. This is closely akin to the metric used for energy: dollars per kilowatt-hour. Thus, instead of a measure of total electrons (energy), you measure photons (light). See the Appendix for details on dimensions and scaling of this metric.

5.2 DATA GATHERING

The data for traditional technologies is using retail pricing of lamps at mass merchandisers and online sources. In the spreadsheet, model data is collected and stored to represent all necessary information for the model. This includes manufacturers' published data on lumen output, power consumption, lifetime in hours and retail costs. Manufacturers' data from the big three, Philips, Osram Sylvania and GE, is confirmed by the Lamp Testing Engineers Conference (LTEC), an industry metrology group, which insures that the three companies perform regular round-robin testing of lamp sources between their photometry laboratories. This insures consistency of testing procedures and test equipment between the large manufacturers of lamp sources.

For each lamp source, the following is recorded:

- Date
- Store name
- Location
- Pricing information
- SKU number
- Model number, if available
- Lumen output
- Lifetime
- Power consumption
- Price

In some cases, if the information is not on the packaging, the model number is used and manufacturers' printed or online catalogs are used to determine other required data.

Figure 5. Mass merchandiser example of lamp displays. Home Depot.

In the initial CoL comparisons, from 2000 and 2001, the cost of LED-based light using this metric was in the $45 – $50 range. Today, using a high-flux LED board of nearly 250 lumens output the Cost of Light has dropped below the $20 range. This example is a lamp product and not a complete luminaire. However the ColorBlaze is a complete RGB light where the CoL is below $30. This unit includes power supplies and some onboard interface as well, and thus reflects a true system cost. Thus the cost for LED-system components and complete fixtures is fast approaching parity and does well when compared to traditional lighting technologies.

Remember too, this comparison is for white light and not colored light. When using gels and filters for traditional sources, the economics favor LED-based systems by a wider margin.

Figure 1 illustrates the confluence of LED trends and the cost of light for LED systems. LEDs are the highest cost component of LED lighting systems. Notice too, the inverse relationship with light output and lifetime; if light output or lifetime can be increased these will have the largest effect on the COL measure. As these improve, the CoL will certainly will become asymptotic over time as can be seen in Figure 1 (see page 34). This curve in the timeline chart is a projection incorporating the 40-year trend in LED cost and performance. Based on developments we see in the laboratories and clean-rooms of the LED manufacturers, we believe that these cost and price trends will continue for at least the next 5 – 10 years.

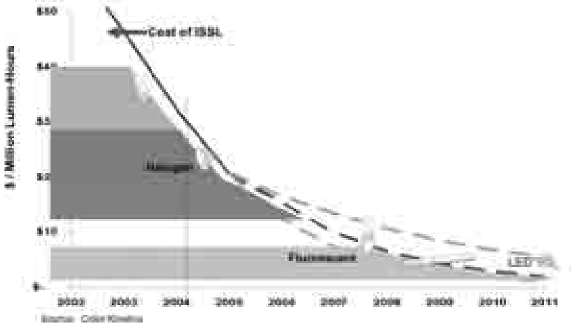
For each category of incandescent, halogen and fluorescent lamps, a representative sample of products available at a mass-merchandiser were used to calculate a series of averages. For one set of calculations, the data source for pricing was a Home Depot.

These prices and products reflect some of the lowest prices available. Additionally, the products available from the home centers are typically not the costlier high quality lamps used by designers. A quick perusal of any of the catalogs from Osram, GE and Philips will show thousands of products spanning a wide range of forms, light output and light quality.

In each of the three lamp categories, about a dozen or so lamp sources were used as examples and the average, median and mode of the Cost of Light were calculated. The average was used for the Cost of Light comparisons. In the fluorescent category however, the Cost of Light for compact fluorescent lamps (CFLs) differs from linear fluorescents due to their different prices. Additionally, traditional fluorescents incorporate a ballast and have additional labeling requirements. These and other differences meant that there were two regions in the Cost of Light curve for fluorescent sources. The calculations do not incorporate weighted averages, but we believe the available selection represents the majority of lamps bought at retail. We do not know the ratios of lamp types in purchased volumes. This may be an additional factor to consider in the CoL calculations.

5.3 RGB AND WHITE

White light can be produced in one of several ways using LEDs. Additive mixing of red, green and blue LEDs will produce white light. Another way is the combination of a blue LED and a phosphor to down convert the light; this is similar, in principle, to the mechanism used by fluorescent sources. Until recently, relatively few white LED-based lighting fixtures have been offered on the market. White LEDs although available, have only recently reached performance and pricing levels where they can be seriously used for a variety of illumination applications. Previously, the high-flux packages were either unavailable or the reported lifetimes were not what was needed for general illumination applications. Now however, a wide range of 1W devices with 25-35 lumen outputs is available and the price has reduced to the point where they make sense for these applications.



The data in the previous figure shows a CoL comparison of LED-based lighting with incandescent, halogen and fluorescent technologies. The high CoL for incandescent and halogen sources arise primarily from energy costs.

5.4 SENSITIVITY

We can also use the Cost of Light model to examine the effects of particular assumptions and particular parameter values such as lifetime or energy costs. By changing those values independently of the others, we can perform an analysis to determine the importance and effect of that parameter. For example, are energy costs more important than lifetime? Do improvements in output dramatically improve the Cost of Light? Examination of the Cost of Light formulation can give some insight into some of these effects as well.

Lumen output has the strongest beneficial effect on the Cost of Light. If efficiency improves so that, for a given amount of power, more light is produced, the Cost of Light can decrease significantly.

For both lifetime and lumen output, as can be seen from the equation, there is an inverse relationship between larger values and the cost of light. This also means that there are diminishing returns, an asymptote, where improvements in those parameters result in little improvement in the Cost of Light. For example, in one analysis, when lifetime is greater than 50,000 hours, there is little improvement in the Cost of Light. Likewise, light outputs above 1000-1200 lumens result in diminishing returns. Since the Cost of Light is a collection of several parameters, however, it is the whole mix that counts.

6. CONSERVATIVE FACTORS

Many of the factors in the comparisons are conservative. Listed here are many additional factors whose incorporation into the model could reduce the cost of light for LED system still further.

- **Lifetime**. The Lifetime definition for LEDs is different from traditional lighting sources. For traditional lighting sources, the lifetime is defined to be at the point at which half of the lamps fail. However, LEDs rarely burn out but do reduce in light output over time; this is termed lumen depreciation. Lifetime for LED systems is assumed to be 75,000 hours based on manufacturers' data and this is only to the point when the output is 70% of initial output. The sources can continue to emit a high percentage of initial light output for a significant period after that period of time.
- **Fixture efficiency**. The LED figures are based on a complete fixture whose output has been measured by a third party NIST-traceable laboratory to IES standards. Complete test results and IES files are available for the fixture as well. The incandescent, halogen and fluorescent figures are for lamps only and not for lamp sources in a fixture or luminaire. Typically, fixtures can reduce the nominal output of a lamp source by 25-60% or more, depending on the fixture and the installation. The Luminaire Efficiency Rating (LER) proposed and supported by several industry organizations is one way to incorporate fixture efficiency. One way in which fixture efficiencies affect the Cost of Light calculations is readily apparent in the CoL for PAR-style flood and spot lamps. Their CoL is relatively low but they are very directional in nature. Thus, the combination of the lamp and a well-

designed fixture can produce an improved CoL over an A-lamp in a recessed fixture. The same is true of LED sources.

- **Ballast efficiency**. Fluorescent lamps, with the exception of compact fluorescents, require separate high voltages to operate and those are provided by a ballast to provide start and operating currents. High-quality electronic ballasts are about 85% efficient and lower quality magnetic ballasts are both noisy and relatively inefficient.
- **Time value of money**. The current Cost of Light model does not reflect the time value of money. Since energy costs are paid at future times and if energy costs are higher for one technology versus another, those future payments can add significantly to overall costs.
- **Rapid progress in LED development**. Reports from several LED manufacturers indicate that recent developments in LED technology are outpacing the predictions of just a few years ago. In separate developments we have seen greater efficacies and higher outputs than were foreseen just a year or two ago. Recently 100lpw LED packages were announced in by Cree.
- **Rapid progress in LED pricing**. Increased production by more companies and specific efforts by countries such as Taiwan have resulted in rapid price decreases in many segments of the LED market, especially in the GaN material-based LEDs such as blue and green. These are placing significant pricing pressure on high-flux HB-LED producers. Nichia for example, recently reduced the prices on white LEDs by 40% and prices on white LEDs are down 8% on average.
- **Energy Costs**. The cost of energy in Japan is significantly higher than in the US. Energy costs in other markets, if higher, can make the analysis even more favorable to the Cost of Light comparison for SSL. There is also no assumption that energy costs will rise or lower in the next several years.

  Other related energy costs are related to additional HVAC loads in facilities due to the additional heating loads placed upon facilities due to energy consumption by lighting products. This factor is also not taken into account. Incandescent and fluorescents, in particular, generate far more heat than light. About 95% of the energy going into an incandescent source results in heat.
- **Labor Rates**. Another conservative factor is that it is assumed in this model that labor rates do not increase over time. Labor rates are based on numbers from the National Lighting Bureau, www.nlb.org.
- **Quality of Light**. A typical measure of light quality is the Color Rendering Index or CRI which compares a light source to a reference source under a palette of other colors. These comparisons are used to produce a normalized scalar between 0-100 to represent the closeness of the light source to a reference source. High efficiency sources such as high-pressure sodium are not considered high-quality sources. The range of CRI for fluorescent lamps in this analysis is 62-85 CRI. White LED sources are already in the 80-85 CRI range and climbing as new phosphor combinations are created. Thus, even today LED sources provide excellent color quality for many applications.
- **Sources**. The data for comparison purposes are from the least expensive sources: mass merchandisers. Supermarkets and discount stores dominate in retail sales of lamp sources but, in the commercial world, electrical distributors and their higher prices often are the source of lamps. It is well known that the big three fight tooth and nail for the mass merchandiser shelves and have very small margins on the products. However, the volumes are significant and help drive down costs for other retail and commercial outlets for their products.
- **The Experience Curve**. In addition to technical and engineering progress, competition and the experience curve will continue to drive down costs. The experience curve, by itself, can drive down prices significantly; prices drop 20-30% for a doubling of production. Indeed, if this does not occur, it is often seen as a sign of poor management. Insights gained from economies of scale and practical experience in production should translate into higher productivity and lower costs.
- **Unique Benefits**. All of the comparisons in this analysis are related to economics and not with particular beneficial features of the light sources other than light output and lifetime. For example, LEDs make sense for environments with high vibration, extreme cold, elimination of thermal radiation, elimination of UV and more. These are separate from the Cost of Light evaluations but impact selection if the lighting applications demand certain performance criteria not taken into account in the Cost of Light. Even aspects of fluorescent sources such as the high-voltage ballasts or Mercury presence may affect decisions for their use.
- **Colors**. These comparisons are based on white light produced through RGB means as well as white LEDs. When producing color, traditional lighting sources require gels or filters to cut out sections of the spectral output and produce a desired color. This is subtractive mixing which makes any light source less efficient. Typical transmission efficiencies for filters are in the 20-80% range, and thus, the relative efficacies of filtered light versus LED additive mixing are substantial and in favor of the LED source.
- **Other Lighting Sources**. The only other lighting technology predicted to have real improvement is HID. But restrike times and ballast costs are unlikely to make a large impact in the general illumination market. HID represents a small fraction of the general illumination market but does well for large area lighting.

7. CONTINUED PROGRESS

The trends of the past forty years brought continually improving LEDs into a number of mainstream applications. The LEDs that comprised the dim displays of early watches and calculators evolved into devices now widely used in high-brightness, direct view indicators such as automotive lighting and traffic lights as well as exit signs. From high brightness indicators they have moved into low- and medium luminance lighting applications such as accent and marker lighting. More recently, white LEDs have followed a similar, albeit rapid evolution into many applications. The rapid improvement of white LEDs is due to the advances and improvements in other LEDs, especially blue LEDs.

Color Kinetics pioneered intelligent LED illumination systems using general purpose microprocessors, networks and high quality LED control. The continuing trends have enabled newer LED-based fixtures with many times the brightness at a fraction of the cost of those early fixtures. LEDs continue their journey into the light; moving again, this time towards general lighting.

APPENDIX: THE COST OF LIGHT – DIMENSIONS AND SCALING

There is some confusion in both the dimensions and final scaling of the CoL, so this exercise details both aspects of the CoL equation. The CoL formulation is as follows:

$$\frac{1}{lumens}\left[\left(\frac{lamp\_cost + labor\_cost}{lifetime}\right) + power * energy\_cost\right]$$

The dimension of the Cost of Light (CoL) metric is in dollars per million-lumen-hours. This is very similar to the metric for the pricing of electricity, a related commodity which is specified in units of dollars per kilowatt-hour. In the CoL version in the IES Handbook, all costs are in cents, lifetime is thousands of hours and energy costs are in cents per kilowatt hour.

DIMENSIONAL CHECK

After removing all scaling factors, since they are dimensionless, then the units can be consolidated to dollars per lumen-hours as shown below:

$$\frac{1}{lumens}\left[\frac{\$}{hrs} + W\frac{\$}{Whrs}\right]$$

Watts are eliminated resulting in:

$$\frac{1}{lumens}\left[\frac{\$}{hrs} + \frac{\$}{hrs}\right] = \frac{\$}{lumen\ hrs}$$

SCALING CHECK

All costs are in cents (0.01 dollars) so that the right-hand side of the CoL formula is:

$$\left[\frac{cents + cents}{khrs} + W\frac{cents}{kWhrs}\right]$$

k is kilo or 1000. Cents, of course, are actually units of dollars/100 so this becomes:

$$\left[\frac{0.01\,dollars}{1000hrs} + \frac{0.01\,dollars}{1000hrs}\right]$$

Now the denominators are equivalent and the scaling of both sides of the sum is the same. Bringing the 0.01 into the denominator gives:

$$\left[\frac{dollars}{100 * 1000\,hours} + \frac{dollars}{100 * 1000\,hours}\right] = \frac{dollars}{100{,}000\,hours}$$

To get to dollars per million lumen hours you need to multiply by an additional factor of 10 in both the numerator and denominator. This additional factor of 10 gives 1,000,000 in the denominator. Upstairs, in the numerator, it appears as a multiplier of 10 and is placed outside the inner sum giving the complete formulation shown above.

The reason that the CoL metric uses a "per million lumen hours" basis is most likely because the desired result is a comfortable number that does not require exponents or give a large range of values.

COLOR TEMPERATURE AND SOLID STATE LIGHTING

Color Temperature is a generally accepted means of describing the color of white light. The term 'temperature' refers to a real temperature of a physics concept called a 'black body'. A black body absorbs all light and energy that impacts it, but conversely, according to thermodynamics, is also a perfect emitter. The close equivalent of this can be seen in such materials as iron, which as it is heated gradually glows hot enough to see in the red, then orange, then yellow up through white and blue. The temperatures that correspond to those colors are the Color Temperatures.

The temperature scale is a real temperature scale, measured in degrees Kelvin. The Kelvin temperature scale is the Celsius scale less 273 degrees. Thus, room temperature is about 22C or 300K. The colors then corresponding to particular temperatures are shown in the curve within the CIE diagram below. The 2000, 3000, 5000 etc are in degrees Kelvin and are shown usually as 2000K, 3000K etc.

Correlated color temperature refers to the closest point on the black body curve to a particular color as defined by its chromaticity value. This is the x, y value on the CIE Chromaticity chart. The reference source(s) are color temperatures that fall on the black body curve

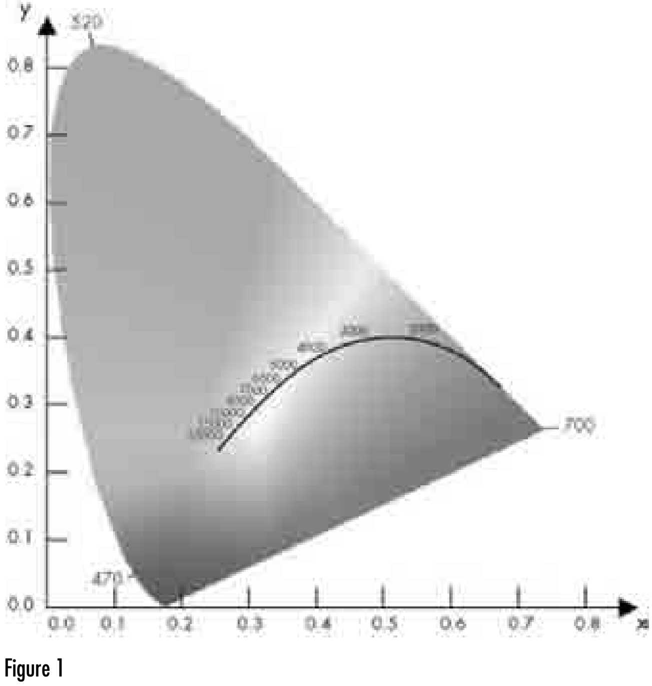


Figure 1

INGRESS PROTECTION OF ENCLOSURES (IP AND NEMA)

WHAT IS INGRESS PROTECTION (IP) AND WHAT DOES IT MEAN?

The acronym IP means many things in different contexts. To some it is Internet Protocol, to others it is Intellectual Property. But in this document, IP refers to Ingress Protection, meaning protection from the environment.

IP is defined under an international classification, IEC 60529, and characterizes levels of protection for electrical enclosures. The protection can be from fingers, dust or water. The standard classification designation is 'IP' followed by two numbers which designate the level of protection.

The first digit of the number designates protection from solid objects and the second digit designates protection from moisture. The levels for the first digit vary from 1 through 6 and the second digit 1 through 8, where a larger number means increased protection. The table below summarizes the various IP designations. As you can see, the greatest level of protection is IP68, which is for continuously submerged enclosures.

The C-Splash-2 is rated IP-68

	First Digit Protection from solid objects	**Second Digit** Protection from moisture
0	No Protection	No Protection
1	Protection against objects >50mm	Protection against vertically dripping water
2	Protection against objects >12.5mm	Protection against water when tilted +/- 15 deg
3	Protection against objects >2.5mm	Protection against spraying water
4	Protection against objects >1.0mm	Protection against splashing water
5	Dust Protected	Protection against jetting water
6	Dust Tight	Protection against heavy jetting water
7	N/A	Protection against temporary immersion

If there is only one class of protection, you may see an 'X' designation in place of one of the digits.

The IP designation is similar to various forms of NEMA enclosure protection. Many designers and contractors are familiar with NEMA type 4 enclosures for example which is approximately equivalent to IP55. Other near equivalent NEMA and IP ratings are shown in the following table:

NEMA Designation	IP
1	10
2	11
3	54
3R	14
3S	54
4 and 4X	55
5	52
6 & 6P	67
12 & 12K	52
13	54

COLOR QUALITY OF INTELLIGENT SOLID-STATE LIGHTING SYSTEMS

COLOR QUALITY

When we view objects under different types of light sources such as incandescent light or fluorescent light, we notice differences in the light and in the way surfaces and objects are rendered under these different light sources. Color quality can be a very subjective measure and there are measures of color quality that allow the designer to compare and evaluate light sources. How do we compare these light sources and what do we compare them to? One way of specifying and comparing light sources is the color rendering index (CRI).

COLOR RENDERING INDEX (CRI)

All light sources are not equal even when, at first appearance, they look the same. For example, two white light sources can illuminate a white surface and the resultant light may appear identical but when illuminating colorful surfaces, objects will render colors differently. So which is correct? How should we judge colors? This is why there is a need for a color metric; a means to judge the quality of a white light source. But of course even nominally white light can be of different tones and colors. The Color Rendering Index or CRI was created in 1965 and later updated to compare different light sources and how they render colors. However, CRI does have limitations and should not be used exclusively to evaluate light quality.

CRI is a specification to assist designers in making a comparison between two lamp sources. CRI is a relative comparison between a lamp source and a reference source. Light sources are compared to the color temperature equivalent of the light source, and a score based on the color shift of a palette of eight colors is used to determine the CRI value. CRI can be used only to compare to sources of the same type. CRI cannot be used to compare the CRI of two sources of dissimilar color temperatures. To compare CRI of two lamp sources, the color temperature of the two light sources should be within 100K.

HOW IS IT MEASURED?

CRI measures the color shift of objects when first illuminated by the light source and then compared when the object is illuminated by a reference illuminant of comparable color temperature. In the Color Rendering Index, a palette of specific colors is used to measure the color difference between a reference source and the source under test. This is termed the General Color Rendering Test and represents a calculation using color sample numbers R1 through R8. Additional colors R9-R15 were later added to CRI and can be used for calculations of the Special Color Rendering Indices. The specification for measuring CRI is given in CIE publication 13.3-1995.

The calculation is the difference between each color sample illuminated by the light source under test and the reference source. The group of samples is then averaged and a score between 0 and 100 is calculated. 100 is the best match between illuminants.

In general CRI values of 80 to 100 are considered good for visual inspection tasks such as in printing or fabrics industries.

WHAT ARE THE LIMITATIONS OF CRI?

There are several limitations to CRI. First, it is a simple scalar value, but light is a rich space of hue, saturation and brightness. No single measure can reveal everything about the quality of a light source. Even light sources with dramatically different spectral power distributions can have identical CRI values yet render colors in very different ways.

Specifically, the color space that CRI uses is obsolete and no longer used for standards except for CRI calculations and determination of correlated color temperature (CCT). The Color Space, termed W*U*V*, is obsolete due to substantial distortion, especially in the red region. The set of colors used for the reference for calculating CRI are pastel colors and lack the richer saturated colors. But, ironically, the most dramatic color shifts are in the more saturated colors! Additionally, with only eight colors used for CRI calculations it provides a sparse set of colors given the breadth of the visible spectrum.

Another common misunderstanding is that high CRI means that the light source will render all colors well. But this is not the case. CRI is measured only with respect to a reference source which is either the blackbody curve below 5000K or a CIE Daylight source above 5000K. The reference must be the closest in chromaticity (color) to the source being tested. Otherwise, the comparison makes little sense. Comparing the CRI of two very different color temperature sources is meaningless but in general, higher CRIs mean less deviation from the reference source.

Here is a simple test: Use an incandescent source to discriminate between dark navy blue and black materials. Although the incandescent source is, by definition, a black body source, it has little output in the blue region. Conversely, a beautiful northern blue sky may have a color temperature of 7500K or greater and have a CRI of 100, yet not render reds effectively.

Even with all the perceived accuracy of a calculation, many designers put their hand in front of the light to see the effect on their skin. This is often a good, though subjective, measure of the quality of a light source.

Another mistaken impression is that a higher CRI value comes closest to approximating natural daylight, but this is incorrect. There is no single measure of natural daylight as the color of the sky and the light from it can vary significantly over the course of a day and viewer location.

In some sense, the CRI measurement method attempts to quantify a subjective measure. However, because the CRI score is affected by the spectrum, it is possible to manipulate the spectrum and produce a higher CRI value. Fluorescent lamp manufacturers have been known to 'game' the CRI metric by shifting the emission points within their lamp spectra. This can shift CRI by several points.

In general though, differences of 5 points in the CRI value do not matter.

To further support the subjective nature of CRI, in one study LED light sources were compared to reference light sources and the LED light sources were preferred over halogen and incandescent light sources for overall color appearance and that CRI had no correlation to people's color preference.

There are several efforts to improve CRI and several organizations, including the CIE, are working at improving the measure. This will take some time and until a new and accepted measure is developed, CRI is a just one way to compare the color quality of light sources. However, given the limitations of CRI, and the lighting designer who must make his or her own judgments and comparisons, it is a generally accepted measure of comparing color rendering properties of illuminants and, until a new measure is developed and accepted, will be the default metric.

POWERING SOLID STATE LIGHTING SYSTEMS

HOW ARE LEDS DRIVEN AND WHAT POWER OPTIONS ARE AVAILABLE FOR LED-BASED FIXTURES?

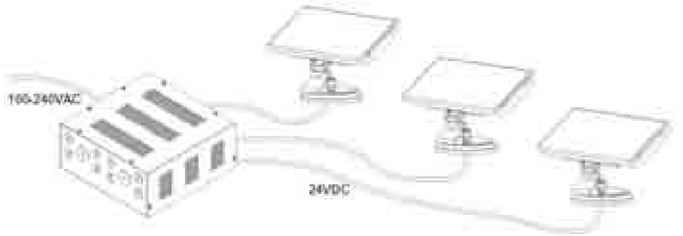
Power options for LED systems can take many forms. Each has performance and cost advantages for particular applications. In general, the trend is towards integration of line voltage power system to facilitate larger scale installations and maintenance.

LEDs are inherently low-voltage devices and voltage levels across each LED are in the range of 2 to 3 volts.

But the important electrical drive characteristic is current control. Current levels should be fixed to insure constant output in color and intensity. Thus, modulation techniques such as pulse-width modulation (PWM) are preferred over other means of driving LEDs. As a result, many LED systems are low-voltage systems running anywhere from 12VDC to 24VDC supply voltages from a power supply to the fixtures. In addition, voltage and current supplied to the LED must be carefully controlled and regulated to insure long life and reliability.

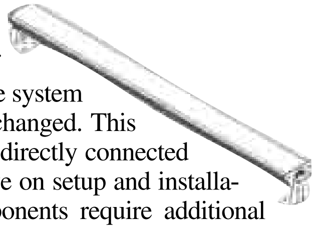
LOW VOLTAGE POWER SYSTEM

The figure below is one example of a low-voltage distribution system using a 'star' configuration where each fixture has a home run of a unified power and data cable back to the power and data supply. Each fixture is individually addressable and the intelligence in the system resides in both the power/data (PDS) supply and the fixture. In Color Kinetics' system, the PDS provides a link to standard DMX data or Ethernet-based control systems.



ON-BOARD POWER INTEGRATION

In another approach, the power supply can be integrated directly into the fixture. This configuration uses a standard switching power supply component incorporated directly into the fixture. The overall control and schematic of the system is similar to the low voltage system shown above but the packaging has changed. This configuration allows the fixture to be directly connected to line voltage. This approach can save on setup and installation costs but these additional components require additional space and increase thermal loads of the fixture. The ColorBlaze, shown here, is an excellent example of this approach – a high-output lighting system for theatrical use that is easy to install by simply connecting it to line voltage.



IN-BOARD POWER INTEGRATION

The final approach is the integration of the power supply directly into the circuitry that provides current regulation and control of the LEDs. This approach, called Powercore, integrates all power and control circuitry to provide a very efficient means of consolidating line voltage conversion and LED current regulation into a single circuit.

Powercore digital power processing technology drives LED systems by integrating power and data management directly into the fixture and eliminating the need for an external power supply. Powercore surpasses traditional power supply technology by streamlining multiple conversion and regulation stages into a single, flexible, microprocessor-controlled power stage that rapidly, efficiently and accurately controls power output to LED systems directly from line voltage. Benefits of Powercore include lowered installation costs, extended runs of fixtures, uninterrupted runs without low voltage supplies, longer lead cabling, simple connection of power and data to a NEMA-type enclosure and more.

POWER FACTOR CORRECTION (PFC)

Powercore also integrates power factor correction into each and every fixture and this has a number of benefits. Power factor is a measure of how effectively equipment converts electric current to useful power output. Low power factor results in higher currents for a given amount of power and low power factor is bad because higher currents require heavier gauge wiring, larger transformers and results in greater losses. Thus, many of the costs of generating and distributing power are related to current, rather than power. Also, low power factor loads can pollute the electricity for other electricity customers as well. Finally, power companies will often bill customers a surcharge if their power factor is too low.

Loads such as motors, transformers, lighting ballasts and low quality power supplies for computers and consumer electronics often have poor power factor. Power Factor Correction irons out the artifacts in current, producing a clean current waveform similar to that of an incandescent bulb, which has perfect power factor.

PFC results in cleaner main power and can reduce the cost of electricity and result in less loss in power distribution systems – yours and the electric company's – by limiting maximum currents. More products can be run on a given circuit with PFC than without PFC.

Color Kinetics's new power technology incorporates active full power factor correction thus mitigating the effects of low power factor. Power Factor in CK's systems can be above 0.995 where a power factor of 1 is an ideal resistive load. This is good for you, your neighbors and the power company. As stated above, in some cases, high power factor can improve circuit loading in your facility and, in some cases, even reduce electrical bills.

There are several relevant standards in this area including Electro-Magnetic Compatibility (EMC) Directives EN61000-3-2 (Harmonics) and EN61000-3-3 (Flicker) under Class C for lighting devices. For the U.S., devices must also meet FCC Part 15 regulations. Color Kinetics' Power Factor Corrected power systems comply with all the above regulations.

DO YOUR FIXTURES AND LAMPS EMIT UV OR IR RADIATION?

THE VISIBLE SPECTRUM

The visible spectrum, the range of colors of light that we can see, is a small part of the electromagnetic spectrum. The entire electro-magnetic spectrum spans from long radio and power waves all the way to ultra-short high-energy X and Gamma-rays. Within that enormous range are regions for commercial radio and television, communications channels, microwave frequencies and more.

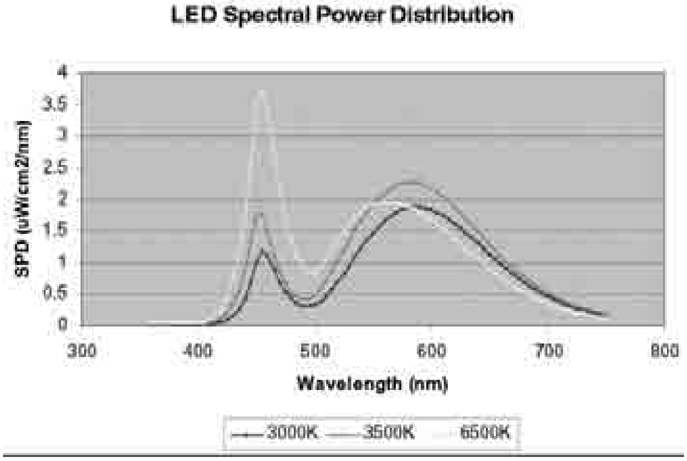
The human eye can sense energy in a very narrow sliver of electromagnetic radiation in a region called the visible spectrum. The wavelengths of electromagnetic energies in this region are measured in nanometers, where one nanometer (nm) is one billionth of a meter. This visible spectrum covers from about 400nm to 700nm. Below 400nm (short wavelengths) is the Ultraviolet (UV) part of the spectrum. Above this region, greater than 750nm, are infra-red frequencies.

ULTRAVIOLET

Ultraviolet (UV) radiation is the region between 40 and 400 nm. The UV spectrum is divided into five subregions: Vacuum UV (40-190 nm), Far UV (190-220 nm), UVC (220-290 nm), UVB (290-320), and UVA (320- 400 nm).

The shorter the wavelength, the higher the energy and the more dangerous it is for people. Fortunately for us, UVC, Far UV and Vacuum UV are not observed in nature because they are absorbed in the atmosphere.

However, UVB and UVA are present from the Sun as well as traditional light sources.



The LED-based color and white light products made by Color Kinetics do not emit outside the visible spectrum. The chart above shows actual measurement of the spectral power distribution of our Iw MR products in all three color temperatures. The same LEDs are identical to those used in the iW Blast, iW Profile and iW Cast products.

White LEDs are actually blue LEDs with a phosphor that converts the blue energy into the red and green regions of the visible spectrum to produce a more uniform broadband pleasing white light source.

INFRARED

Additionally, as you can see from the chart, above 750nm, the beginning of the near-infrared region, little to no energy is radiated. All thermal energy is conducted through the housing and not radiated in the beam. No UV, no IR. The LED systems emit only a 'cold' beam with only visible light.

EMERGENCY LIGHTING TEST

Power Factor Inc.

These are the specifications for an emergency lighting system used by Power Factor Incorporated:

1) Map locations of each unit using a floorplan of building or hand draw a floorplan. Use symbols to designate type units. We use a triangle for Exit signs and a square for emergency lighting units.
2) Assign a location number to each unit. We use E in front of the number for Exit signs and L in front of the number for Lighting units.
3) Open unit and check voltage across the battery. This is the float voltage. Document the float voltage.
4) Compare to chart for correct float voltage and battery type. Note: There is pure lead in cylinder shape cases.
5) Run a 5 minute test by pushing test button or disconnecting AC power to the unit until voltage settles or until 5 minutes is up, whichever comes first. Monitor voltage during this test. Note the end voltage.
6) Compare end voltage to chart.
7) If Voltage falls below chart levels, replace the battery.
8) Document parts used.

CHARGER SPECIFICATIONS

The chart below depicts the "flat voltage" settings required to properly charge the unit's battery. The tolerance of these settings is +/- .05 VDC.

Nominal Voltage	Wet Cell Lead Acid	Wet Cell Nicad	Maint. Free Gel Cell	Maint. Free Pure Lead
4 volt	n/a	n/a	4.56v	4.70v
6 volt	6.60v	1.43v/cell	6.85v	7.05v
12 volt	13.20v	1.43v/cell	13.70v	14.10v
24 Volt	26.40v	1.43v/cell	27.40v	28.20v

Fig 1. Float Setting Chart

BATTERY SPECIFICATIONS

If battery voltage is less than chart voltage, replace battery.

Nominal Voltage	Wet Cell Lead Acid	Wet Cell Nicad	Maint. Free Gel Cell	Maint. Free Pure Lead
4 volt	n/a	n/a	3.65v	3.75v
6 volt	5.30v	1.15v/cell	5.50v	5.65v
12 volt	10.05v	1.15v/cell	10.95v	11.30v
24 Volt	21.00v	1.15v/cell	21.95v	22.60v

Fig 2. Battery Discharge Comparison@ 5minute Rate

EMERGENCY LIGHTING BATTERY CHARGERS

The batteries of an emergency lighting unit must be kept in a ready state in order to provide emergency power during a power loss. This is done by connecting a charger to the battery to maintain the charge during stand-by mode.

The specific application will govern the type of charger and charging method used to keep a battery in a ready state.

There are three basic chargers;

1) **Constant potential charger** – This is the most common and is used where a long term charge is expected. It reduces overcharge current and prolongs battery life. As the battery terminal voltage rises, the current to the battery is reduced. When the regulated voltage is reached, a final trickle current of 10 to 100 milliamps is supplied to keep the battery at ready state.
2) **Constant current charger** – This is used where the battery will be cycled regularly with a relatively short period of overcharge. Normal charging is completed in 16 to 24 hours. A relatively stable current is used to charge the battery for a complete charge cycle. A voltage or time monitor is used to turn the charger on and off.
3) **Dual Rate Charger** – This provides rapid charging of a constant current charger and low float current of the constant potential charger. A relatively stable current is used to charge the battery during the first portion of the charging cycle. Once it reaches a predetermined voltage, the current begins to reduce until it reaches float voltage. At that point, a trickle current is supplied to the battery to offset self-discharge of the battery.

Note: In many cases, if the indicator light stays bright on a dual rate charger for more than 24 hours, it is likely the battery is bad. What is happening is the charger is trying to charge a battery that will not accept a charge.

TROUBLESHOOTING

UNIT IS DEAD

NO AC POWER PRESENT. APPLY AC POWER

AC LOCKOUT

Most manufacturers have a standard feature called AC Lockout. This feature prevents battery discharge through the DC transfer circuit prior to the initial application of AC power. The AC Lockout feature allows the unit to be installed with the battery connected, completely ready for operation at any time prior to the availability of AC power. The purpose of the AC lockout is to allow the contractor the freedom to install the equipment when it is convenient for him/her and not have to return later to connect the battery after the circuit is energized with AC power.

Note: An important fact regarding AC lockout is that, in being a transistor controlled circuit, it is subject to the low leakage currents inherent with these semiconductor devices. In order to avoid battery damage, it is recommended that the unit be energized within 30 days after installation.

BATTERY HAS GOOD VOLTAGE, BUT UNIT DOES NOT WORK.

Batteries must be checked under load. This means when you check the battery voltage you must disconnect AC power or hold the test switch. This will allow lights to come on and load the battery. Only now will you see the true voltage of the battery. If battery voltage drops below 87.5% of battery nominal (6V battery is 5.25V), the battery is bad.

Note: When a battery is bad, the battery voltage is likely to drop below the 87.5% mark very fast and rise back up to original voltage. This is the LVD doing its job.

LVD – LOW VOLTAGE DISCONNECT

This circuit is in most equipment using lead acid batteries and is required by the National Electrical Code for emergency lighting equipment. It is designed to disconnect the battery at aprox. 87.5% of battery nominal. It serves two main purposes.

1) **Maintains a constant level of light during discharge.** (If battery would drop lower than 87.5% of nominal, lights would start to get dimmer and not provide the same level of light.)
2) **Protects the battery from deep discharge.** Lead acid batteries discharged below 87.5% of nominal will decrease in capacity and not perform properly.

BATTERY TESTS OK BUT UNIT STILL DOES NOT WORK.

Check the light bulbs

In cases of older units or units that are frequently used, it is possible that all of the light bulbs can be burnt out, usually in cases where units are neglected and have not been serviced for quite some time.

Check voltage at PC board for DC voltage where lamps connect while pushing test switch or removing AC power. If no DC is present, recheck battery connections. If all connections are good, it is possible the transfer portion PC board is bad. In many units, this circuit can be damaged if battery was installed with polarity reversed even for a very short time. Check at lamp socket for DC voltage. If DC is present, the bulbs are burnt out or the socket is defective. If no DC voltage is present, check all connections.

THE EVOLUTION OF FLUORESCENT LAMPS

Yara Andraous, Project Manager, Osram Sylvania

In 1938, the first fluorescent lamp was introduced. Since then, many advances have been made in fluorescent technology including; efficiency, size, colour and life. Although fluorescent lamps are available in many different sizes and shapes, the basic components and operating principles of most fluorescent lamps are the same.

Fluorescent light sources are a member of the larger family known as gas discharge lamps, whereby an electric arc inside a gas fill leads to light emission.

The first fluorescent lamps to be introduced were T12 types. The designation 'T' is indicative that the lamp is tubular in shape, and the '12' refers to the diameter of the bulb in eighths of an inch (i.e.: a T12 lamp is 1.5 inches in diameter).

Energy saving T12 lamps were developed in the 1970s to retrofit existing lighting installations. Although wattage ratings of these lamps are 15-20 per cent lower than full wattage lamps, the light loss is approximately 20 percent. In other words, the light loss is equivalent to the energy savings when using energy saving T12 lamps; an excellent idea during the energy crisis in the 1970s, but not so practical for today's applications

Today, on average, T12 sales in Canada have been decreasing at a rate of 10% per year. There is a natural migration away from T12s because of their high energy consumption and lower light quality. Yet today, T12s still outsell any other linear fluorescent lamp in general lighting applications. In order to address this issue, Natural Resources Canada has passed legislation to eliminate the high energy consuming T12 magnetic ballasts for both 4 ft and 8ft T12 lamps. By April 1, 2010, manufacturers will not be allowed to manufacture these ballasts. In other words, after April 1, 2010, anyone wishing to replace a T12 magnetic ballast will have to retrofit their entire fixture to an alternate fluorescent light source, such as T8.

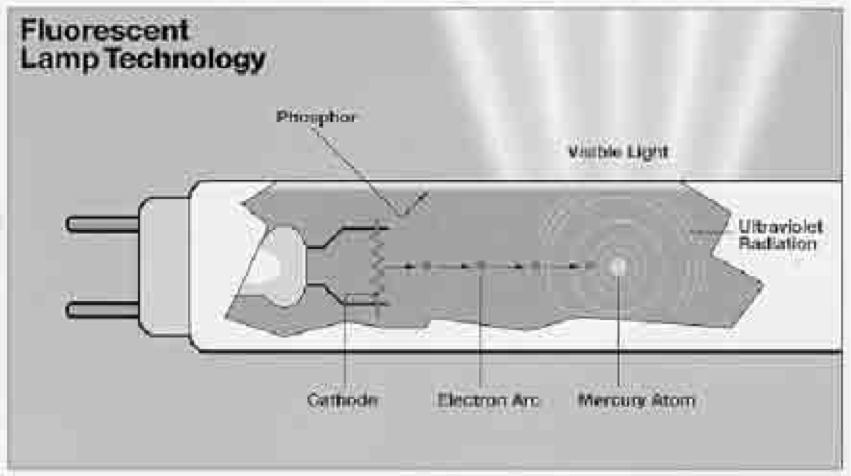
The T8 fluorescent light source is the most popular type for retrofits today. The T8 lamp provides full light output compared to T12 fluorescent lamp in the same fixture, but yields 30 to 45 per cent in energy savings. These lamps require a ballast change to convert existing fixtures to T8 lamps.

The use of extended performance (XP) T8 lamp combines increased lumens per watt (efficacy) and lumen maintenance (95% compared to 90%) with a longer rated life (30,000 hours compared to 20,000 hours for standard T8 lamps at 3 hours per start), T8 XP lamps are making a significant impact in the fluorescent lamp market. T8 XP lamps, when operated on a high efficiency (QHE), low ballast factor electronic ballasts will provide equivalent light levels to a standard T8 on a standard electronic ballast with an additional energy savings of 19%.

Technological advancements of energy saving lamps has progressed so much, that the use of a 28 watt energy saving T8 lamp will save 12.5% in energy compared to a standard T8 lamp without sacrificing light output; a far cry from their T12 predecessors.

Increased research efforts have lead to the reduction of the diameter of the fluorescent tube. An important achievement has been the advent of the T5 lamp, with its 5/8 of an inch diameter. This has opened up a new world of possibilities for sleek innovative fixture designs. T5s have so far been used mostly for high bay applications, replacing the infamous 400W metal halide lamp, and in indirect fixture applications. However, with the development of new T5 technologies, this will change.

The newest development is the T5 Pentron C High Output (HO) lamp family, a result of a dramatic change in the design and manufacture of the T5 HO lamp. For the first time, amalgam technology has been incorporated in the manufacturing process of a linear fluorescent lamp resulting in a lamp which tolerates a much broader range of ambient temperature with minimal light

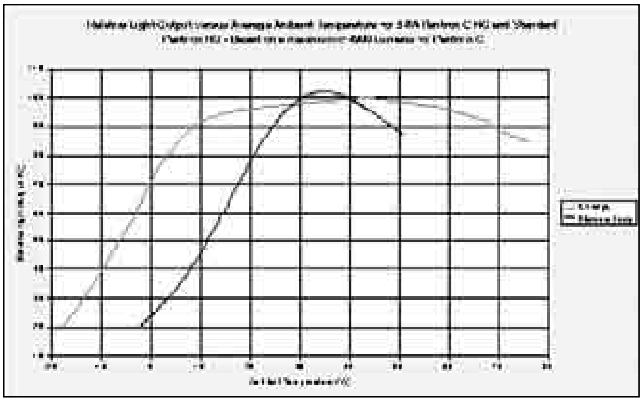


BASIC COMPONENTS

BULB	Typically a straight glass tube
PHOSPHOR	A coating on the inside of the glass bulb which transforms UV radiation to visible light
BASE	Several different types are used to connect the lamp to the ballast and support the lamp in the fixture
CATHODE	Located at each end of the lamp and coated with a material which emits electrons
GAS	Argon or a mixture of inert gas at low pressure (sometimes Krypton)
MERCURY	Minute quantities of liquid mercury are placed in the bulb to give mercury vapour.

loss. The standard 54W T5 HO lamp produces maximum light output at an ambient temperature of 35C, but drops substantially if the ambient temperature falls to 25C or increases to 45C. The Pentron C HO lamp will maintain a minimum of 90% of its light output over a range of 60C, from 10C to 70C.

With the many advantages of the PENTRON C HO lamp, they are sure to overtake predominantly T12 applications such as indoor and outdoor signage, parking structures, warehouse applications, indirect lighting, etc. This same technology is also being added to compact fluorescent lamps with the introduction of the new DULUX L FT55 C, a high lumen single-ended T5 twin lamp. As a result of innovation in compact fluorescents, many new products are immerging, including the DULUX L Supersaver 28-watt, high lumen, single-ended T5 twin tube lamps.



These are direct, high efficiency replacements for 40-watt lamps (for use on instant start, electronic ballasts). DULUX L Supersaver lamps boast a lamp efficacy of up to 100 lumens per watt. A simple lamp replacement with these lamps in a 3-lamp luminaire results in 6 percent energy savings, while maintaining similar light levels. The lamps have a life of 20,000 hours at 12 hours per start. Their improved performance makes them ideal for lighting applications including 2x2 recessed coffer, indirect and wallwash type luminaires.

Further innovation has lead to the introduction of a T2 miniature fluorescent lamp featuring excellent luminous efficacy with only a quarter inch diameter bulb. This lamp is ideal for space saving fixture designs such as those required for under cabinets and displays.

The colour and quality of the light produced by a fluorescent lamp depends on the chemical composition of the phosphor coating on the inside of the lamp. By combining different phosphors in varying proportions, it is possible to produce lamps in a wide variety of colours. With the introduction of rare earth phosphors, fluorescent lamps can now have both high light output and good colour properties.

With environmental awareness becoming increasingly important, T8, T8 XP, T8 XPS and T5, T5 HO, and PENTRON C HO reduced-mercury lamps are widely available. By decreasing the mercury in the lamp and adding other environmentally friendly components, these light sources will achieve similar luminous efficacy but with much less environmental impact.

An exciting technology that is now commercially available is the Inductively Coupled Electrodeless (I.C.E.) fluorescent lamp. The ICE lamp features a modified fluorescent tube that has no internal cathodes but utilizes an externally applied electromagnetic field to stimulate the mercury atoms. Since standard fluorescent lamp life is determined by the life of the cathodes (typically 20,000 hours), the ICE lamp life is rated at 100,000 hours. With no parts to wear out, the lamp lasts so long that it need never be changed.

When used as a system with electronic control gear, the lamp has a luminous efficacy of up to 80 lumens/watt, outperforming all previous electrodeless lamps. It also achieves a luminous flux that has not yet been achieved by any fluorescent lamp. The lamp and ballast system features instant flicker-free starting and emits a pleasant light that does not flicker during operation. The ICE lamp features a CRI (80) equivalent to that of standard T8 lamps and is available in a variety of colour temperatures.

The extremely long life of the lamp makes it ideal for applications where relamping is awkward and expensive or where safety is of primary importance. The long service life reduces the high cost of relamping, while the dimensions of the lamp mean that it can be used in low-profile fixtures for innovative lighting design.

Street lighting installation with Icetron lamps

Fluorescent lamps are in a never-ending state of evolution. Manufacturers are constantly working towards smaller, more efficient and environmentally friendly light sources for use in a variety of applications.

NEC CHANGES IMPACT LIGHTING CONTROL PANELS, METAL HALIDE LIGHTING - PART I

Craig DiLouie, Lighting Controls Association

Nearly all 50 states rely on the National Electrical Code (NEC), published as a standard by the National Fire Protection Association (NFPA), as the code they use to regulate electrical installation in new construction and renovation projects.

The NFPA recently published the 2005 version of the NEC, which is enforceable in all states and municipalities that adopt it. Several provisions in the new Code affect lighting, including lighting control panels, metal halide fixtures, and disconnecting fluorescent fixtures prior to servicing.

The 2005 NEC went into effect January 1, 2005, but adoption can vary from state to state (and municipality to municipality). Based on the rate of adoption of the 2002 NEC, several states may adopt the Code right away, with about half the states adopting it in 2005. At the time of writing, according to the National Electrical Manufacturers Association (NEMA), several states, including Texas, North Carolina and New Hampshire, have adopted the 2005 NEC, with various timelines for enactment.

PROTECTED LAMPS IN METAL HALIDE FIXTURES

Metal halide (MH) lamps have the possibility of “non-passive failure” at end of life, which can cause hot quartz elements to exit the fixture.

The 2005 NEC addresses non-passive failure in Article 410.73(F)(5), “Metal Halide Lamp Containment,” which states: “Luminaires (fixtures) that use a metal halide lamp other than a thick-glass parabolic reflector lamp (PAR) shall be provided with a containment barrier that encloses the lamp or shall be provided with a physical means that only allows the use of a lamp that is Type-O.”

This means that either an enclosed fixture can be specified (with any type of lamp, including Type-E and Type-S), or an open-optic fixture can be specified that only operates Type-O lamps. These open fixtures feature a socket that can only operate Type-O lamps.

Type-O lamps are protected lamps, typical for 175-1500W sizes, that have additional containment around the arc tube. They feature a special base (EX39) so that they can only operate in compatible special sockets.

Fixtures with thick-glass PAR MH lamps are exempt.

To an extent, the lighting industry has already been applying this rule to indoor open MH fixtures that operate lamps less than 350W. NEC is now applying it to all open MH fixtures. In the future, UL may review this requirement and if they adopt it as a standard for fixture manufacturers, the requirement will truly become national, since not all states may adopt the 2005 NEC quickly.

This requirement is not expected to significantly change specification practice. Specifiers will need to make sure that enclosed fixtures are suitably rated, and make sure open fixtures have a physical means so that they only operate Type-O protected lamps. In addition, they will have to make sure that they specify Type-O protected lamps. Overall, this Code requirement is expected to simplify the MH systems options that are available.

METAL HALIDE AND MERCURY VAPOR FIXTURES IN SPORTS, MIXED-USE AND ALL-PURPOSE FACILITIES

In these facilities, the lamp’s outer bulb can be broken during normal use of the space. When the bulb breaks, glass can fall out of the fixture into occupied space. In addition, the arc tube may continue operating, resulting in possible overexposure to UV radiation among occupants, which can cause sunburn and a burning sensation around the eyes.

The 2005 NEC addresses this situation in Article 410.4(E), which states: “Luminaires subject to physical damage, using a mercury vapor or metal halide lamp, installed in playing and spectator seating areas of indoor sports, mixed-use, or all-purpose facilities, shall be of the type that protects the lamp with a glass or plastic lens. Such luminaires shall be permitted to have an additional guard.”

NEC requires that these lamps be completely enclosed with a glass or plastic lens to protect the lamp from damage. The fixture can contain an additional guard such as an external screen or cage, but this is not a substitute for the required enclosure.

DISCONNECTING MEANS DURING RE-BALLASTING

Industry data shows that a leading cause of fatalities among electricians is electrocution while working on 277V lighting systems. Some believe that this is partly because electricians are often pressured to change out ballasts while circuits are energized to avoid removing light from the area of servicing, causing them to ignore applicable warnings, instructions and training.

NEC has addressed this situation in Article 410.73(G), “Disconnecting Means” which addresses changes to how fluorescent fixtures are disconnected prior to electrical work to prevent the possibility of shock hazard. This Article states: “In indoor locations, other than dwellings and associated accessory structures, fluorescent luminaires that utilize double-ended lamps and contain ballast(s) that can be serviced in place or re-ballasted must have a disconnecting means, to disconnect simultaneously all conductors of the ballast, including the grounded (neutral) conductor if any. The disconnecting means must be accessible to qualified persons.” There are a number of exceptions to this rule, which cover installations or conditions where rule variations are needed or it isn’t practical to apply the rule, such as hazardous location fixtures and fluorescent exit signs.

This requirement, however, will not become effective until January 1, 2008, to allow manufacturers time to comply. Basically, it appears to be a 2008 NEC requirement.

LIGHTING CONTROL PANELS

Industrial control panels used to control such systems as lighting, conveyor systems and air conditioning are, in many cases, manufactured in the field. The individual devices used in the system may be listed, but not the resulting panel itself. This has been a troubling issue for both installers and inspectors, as increased use of the panels has been accompanied by increased misapplication.

Specifically, in the event of an overcurrent situation, the energy level may exceed the short circuit current rating (SCCR) on a component in the system.

First, it would be useful to define what constitutes an "industrial control panel", since this term is not very commonly used in commercial applications.

NEC Article 409.2 states: "Definitions. Industrial Control Panel. An assembly of a systematic and standard arrangement of two or more components such as motor controllers, overload relays, fused disconnect switches, and circuit breakers and related control devices such as push-button stations, selector switches, timers, switches, control relays, and the like with associated wiring, terminal blocks, pilot lights, and similar components. The industrial control panel does not include the controlled equipment."

"The key to this definition is that the panel contains two or more devices as stated in the NEC definition," says Scott Jordan, Marketing Manager for Square D/Schneider Electric. "As such, any enclosure containing a plurality of switching relays, an enclosure containing a relay and timer, or an enclosure containing a relay and a terminal block would fall under the definition as being classified as an industrial control panel."

"As such," he adds, "virtually all lighting control panels, supplied either by a manufacturer as a complete assembly or custom built on a job site, will need to meet the requirements of NEC 409."

The 2005 NEC addresses industrial control panels in a new section, Article 409, which is designed to facilitate safe installation as well as inspection. Previously, industrial control panels were installed based on general requirements from other NEC articles and special rules in some states. The new Article 409 covers general-use industrial control panels that operate at 600V or less. Article 409 impacts the way control panels are designed and built to ensure the entire panel and related components all meet a defined SCCR for the application, and that the panel is marked with the appropriate SCCR.

NEC Article 409.110 states: "An industrial control panel shall be marked with the following information that is plainly visible after installation: (3) short circuit rating of the industrial control panel based on one of the following: (a) short circuit current rating of a listed and labeled assembly; (b) short circuit current rating established using an approved method; FPN: UL 508A-2001 Supplement SB is an example of an approved method."

The SCCR provision in UL 508A is also new and becomes a national standard in April 2006.

NEC also requires: "SCCR for a component or equipment shall be equal to or greater than the available short-circuit current where the equipment is being installed in the system."

This NEC Article applies to OEMs, machine builders and panel builders, but it affects other professionals downstream as well. For example, if an existing panel is relocated, the state may require that 2005 NEC and its rules apply. If a panel is relocated after it is installed in compliance with 2005 NEC, the SCCR of the panel must be adequate for the new location. And inspectors will be looking for proper labeling on panels in new and updated installations.

LINEAR FLUORESCENT DIMMING BALLASTS: TECHNOLOGY, METHODS, PROTOCOLS - PART II

Dimming linear fluorescent lamps can provide a number of significant benefits to owners of commercial lighting systems:

- Flexibility, enabling the lighting system to adapt to multiple activities and changing space needs.
- Cost savings, derived from direct energy savings as well as load reduction during peak demand periods, which can be accelerated by using dimming ballasts in a system that can also include occupancy sensors, daylight sensors and time-clocks.
- Greater worker comfort, satisfaction and performance, achieved by allowing occupants to choose their own light levels.
- Increased lamp life for applications where lamps can be dimmed instead of frequently switched.
- Dimmable fluorescent systems combine the long life and energy efficiency of fluorescent lamps with the controllability and full-range dimming capabilities of incandescent systems. In this white paper, we will discuss how linear fluorescent lamps are dimmed, then compare popular methods for dimming with pros and cons of each.

DIMMING BALLASTS

Linear fluorescent lamps produce light when an arc of electric current is established across the lamp from one cathode to the other, causing the gas to emit energy that is converted into visible light by the phosphor coating the inside of the glass bulb. Fluorescent lamps require a ballast to operate, an electrical device that provides the proper starting voltage to initiate the arc and then regulates the current flowing through the lamp.

The ballast can be configured so that it 1) receives a signal from a control device and subsequently 2) changes the current flowing through the lamp, thereby achieving a gradual controlled reduction in lamp output. The characteristics of the control signal affect the duration and extent of the change in current and subsequent lamp output.

Dimming ballasts are available for operation of linear and compact fluorescent lamps. In this article, we will focus on linear fluorescent lamps.

Most commercially available dimming ballasts for operation of these lamps are electronic rapid-start or programmed-start ballasts, and all linear lamps operated by these ballasts feature bi-pin bases typical of rapid-start lamps.

Rapid-start ballasts preheat the cathodes with a small voltage, which reduces the amount of voltage needed to start the lamp. After preheating the cathodes, the ballast provides the high voltage required to initiate the arc.

Programmed-start ballasts are rapid-start ballasts that preheat the electrodes more accurately to minimize damage to the electrodes during the start-up process (according to a program) and therefore can optimize lamp life. While supplying the preheat voltage, the ballast minimizes the lamp voltage, thereby reducing glow current during this phase with its associated degrading effect on lamp life. As a result, programmed-start ballasts can provide up to 100,000 starts, ideal for applications where the lamps are frequently switched, such as space with occupancy sensors.

DIMMING METHODS: ANALOG VS. DIGITAL

Several methods can be used to achieve the dimming effect. Because the dimming ballast must be able to communicate with connected controllers, the method becomes the basis for a protocol, or common operating parameters adopted by all manufacturers of dimming ballasts and controllers that use that method. This assures interchangeability between the ballast made by a particular manufacturer and various controllers made by controls manufacturers. Check the ballast manufacturer for compatibility between its ballasts and various controls.

The primary methods are:

- **Analog:** The analog electronic dimming ballast includes components that perform these functions: electromagnetic interference filtering, rectification, power factor correction and ballast output to power the lamp. There are several analog methods, including 0-10VDC, two-wire phase-control, three-wire phase-control and wireless infrared, with 0-10VDC being most popularly used.
- **Digital:** The digital electronic dimming ballast includes components that perform these functions: electromagnetic interference filtering, rectification, power factor correction, a micro-controller and ballast output to power the lamp. The micro-controller functions as a storage, receiver and sender of digital information. The micro-controller can store the ballast address, receive control signals and send status information.

Analog dimming systems are established and common, while digital dimming systems are relatively new to the industry. Both provide the essential function of controlling the lamp output based on input from a control device. Both enable the construction of networks of controls and ballasts wired to local and central points where control signals can originate, either manually or based on a program.

Analog is the standard dimming method, typically presents a lower cost, and is compatible with a wide range of common control devices. The dimming ballasts can be on a low-voltage or line-voltage control circuit. Analog ballasts and controls are compatible as long as they are configured to the same method – e.g., 0-10VDC, etc.

Digital provides a higher degree of granularity of control capability, such as ability to individually address and group the ballasts, gain feedback information from ballasts, manage a variety of zones and scenes, and provide a lighting system that can easily accommodate changes over time.

PROTOCOLS

Dimming ballasts must be configured to understand and act upon the control signal coming from a control device over either low- or line-voltage wires. To ensure compatibility, protocols have been developed around the various dimming methods.

It should go without saying that items designed to operate on different protocols are not compatible and should not be operated together. Doing so will result in the dimming system failing its purpose, as well as potentially damaging the equipment.

Analog: There is currently no standard for the operation of analog dimming ballasts. While there is a 0-10VDC control ANSI standard for the entertainment industry, it does not apply to dimming ballasts. As a result, equipment may work well together as a system but dimming performance may not be consistent among different ballast types and ballasts made by different manufacturers. A 5V signal for one ballast might result in a 50% dimming level but 30% on another, for example.

Digital: For digital ballasts, the Digital Addressable Lighting Interface (DALI) protocol, part of Europe's IEC Standard 60929, provides a standard. DALI offers the possibility of true interchangeability between ballast manufacturers and defines light output for all levels of dimming signals, ensuring consistent dimming performance across all dimming ballasts regardless of type or manufacturer. This ensures that different ballast types can mingle in the same control area and simplifies commissioning.

METHODS/INTERFACES

The dimming method is an important consideration, since it often defines the range of possible change in the lamp output and also the wiring configuration, which in turn affects capability as well as cost. As with everything in lighting, there are tradeoffs.

Digital: Digital ballasts are recommended to use a Class 1-rated 5-conductor cable that uses one hot (live), one neutral, one ground and two polarity-insensitive control wires, all routed together in the same conduit. It is also possible to install the ballasts and controls as a Class 2 installation, in which case the control wires must be routed through separate conduit as the power wires. Check with the ballast and controls manufacturers whether their products are rated for Class 1 installation.

The other digital protocol is proprietary, developed by Energy Savings Inc. (ESI), which was purchased by Universal, whose digital ballasts are now marketed under the AddressPro brand.

Analog (0-10VDC): Dimming is accomplished by controlling the amplitude of the current flowing through the lamp via reduction in the lamp power. As lamp power decreases, lamp voltage increases proportionally to maintain heating of the lamp cathodes and prevent the lamp from being extinguished.

0-10VDC ballasts use four wires, with two line-voltage leads (hot and neutral) to power the ballast and two low-voltage control leads to change the light level. Depending on wire insulation and control switch ratings, the control wires may either be routed in the same raceway (Class 1) or in a separate raceway (Class 2). In general, the system may be installed as Class 1 if the control wires carry the same voltage rating as the power wires and the control device is rated for Class 1.

This wiring scheme adds labor and material costs to the installed system cost, but enables the dimming ballast to be linked to other ballasts and control devices in a larger system, which in turn can be linked to local occupant controls and central control.

Typically, 0-10VDC ballasts have violet and gray control wires. The gray wire is internally connected to provide a ground reference.

When the voltage level is near or above 10VDC, the ballast responds with full light output. As the voltage decreases, the ballast reduces light output. The ballast can also be connected to a switch or relay to enact bi-level control, providing full light output when the switch opens and reducing it to a specified minimum when the switch closes.

Note that some manufacturers provide command regions in the 0-10VDC range; a signal less than 0.3V might signal the ballast to shut down, for example. Be sure that the specified controllers are compatible with any such added feature for the chosen ballast.

Analog (Two-Wire Phase-Control): Also called AC dimming, phase chop dimming or two-wire dimming, phase-control dimming entails "reading" the AC power supply signal's "starting point" or zero crossing point, then turning on the current after a preset waiting time. This "cuts out" part of the cycle and results in dimming. The extent of the waiting time, usually 0-8.3 milliseconds or one-half the waveform, is related to the dimming level.

Phase-control ballasts use the same two line-voltage leads for both power and ballast control. The ballast receives the dimming signal through the dimmed hot wire connected to the power line.

Because the standard wiring configuration is utilized, phase-control dimming ballasts represent a lower-cost dimming solution, typically found in architectural dimming applications such as conference rooms, boardrooms and individual offices. It is also ideally suited to retrofits, stand-alone applications and cost-sensitive projects. In addition, the control signals are less sensitive to interference than low-voltage analog signals.

Currently, Advance is the only manufacturer that offers a full line of phase-control dimming ballasts (Mark X Powerline). Lutron makes available a limited offering (Tu-Wire). OSRAM SYLVANIA and Universal Lighting Technologies have discussed developing such ballasts and offering them in the near future.

Analog (Three-Wire Phase Control): The three-wire phase control configuration is based on the original magnetic dimming ballast conventions from the 1960s. This control method uses a third wire (in addition to hot and neutral) to carry the (typically) phase control signal to the ballast. All three wires are rated Class 1 and can be run within the same conduit. Lutron manufactures three-wire phase-control dimming ballasts (Hi-lume, Compact SE and ECO-10).

Wireless Infrared Control: Some manufacturers also have wireless infrared control available. This method uses an IR transmitter to perform the control function and does not require any additional wires. The dimmer is included either in the ballast or as an additional device in the light fixture. This is a good retrofit solution, and allows for occupant fixture control. These types of ballasts are available from Lutron (ECO-10).

THE BEST SOLUTION (WHEN CHOOSING ANALOG BALLASTS)

A major difference between the three main analog dimming ballasts is the equipment required to control them. They are all "hard-wired" to the control circuit or zone, and one control device can control one zone. All of the ballasts wired to the same purple and gray wires (0-10VDC) and wired to phase-cut dimmed leg for two- and three-wire control will be controlled together. For building-wide control, these control wires must be connected to some type of dimmer which is then connected to the other dimmers and some type of building-wide network, presumable with some type of central control.

THERE ARE TWO MAIN SYSTEM TOPOLOGIES FOR THIS SYSTEM:

- **Centralized:** All dimming control wires for an area are pulled back to a dimmer cabinet or cabinets mounted in the electrical closets, and then these dimmer cabinets are connected together and to a central controller via a network.
- **Distributed:** The dimming control wires are connected to a device that is mounted nearby, such as on the wall or in the plenum, and then these control devices are all connected together and to a central controller via a network. Either topology can be used to achieve building-wide control.

0-10VDC: 0-10VDC ballasts have the advantage of needing only small low-voltage components in the control device, so they are easiest to use in a "distributed" system. 0-10VDC control allows the on/off control to be separated from the dimming control, allowing a combination of centralized switching and distributed dimming equipment to be used.

Two-Wire Phase-Control: Two-wire phase-control ballasts have the advantage of not needing any additional wiring between the control device and the ballast, which makes them very attractive for new centralized dimming applications as well as retrofits. They also don't require a separate switched power leg, so the hardware required to dim these ballasts is exactly the same as the hardware required to dim incandescent loads. This means that most (if not all) dimmer manufacturers include a way to adjust the dimming curve of their dimmers to allow the control of two-wire ballasts from their dimmer cabinets.

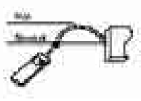
Three-Wire Phase-Control: Three-wire phase-control ballasts draw very little current on the dimmed leg, which means that they can be dimmed without causing much heat to be generated at the dimmer. This allows devices that are intended only for this type of load to be smaller and also appropriate for use in a distributed system.

While considering all of the factors, the best solution for any given application, of course, depends on the application need. For example, is the primary goal energy savings, visual need or some other application need? What kind of dimming performance is required – 100% to 1%, 5% or 10%? The choice of dimming ballast often comes down to specifier preference, dimming system compatibility, total installed cost (including wiring), and availability for the fixtures being used.

0-10VDC

Two-Wire Phase-Control

Three-Wire Phase-Control



Wireless Infrared

FINDING THE BEST SOLUTION (ALL BALLASTS)

The major dimming methods are compared side by side in Table 1:

Table 1. COMPARISON BETWEEN BALLAST CONTROL METHODS.

Digital	0-10V	Two-wire Phase Control	Three wire Phase Control	Infrared Control
Dimming range: 1%-100% dimming ballasts are available.	Dimming range: 3%-100% ballasts are available for T8 lamps; 1%-100% ballasts are available for T5HO lamps.	Dimming range: 5%-100% available for T8 lamps; 1%-100% available for T5HO lamps.	Dimming range: 1%-100% available.	Dimming range: 1%-100% available.
Wiring configuration: It is recommended that a five wire Class 1 rated cable is used. The ballasts and control devices must be Class 1 rated. Otherwise, the control wires have to be routed separately from the power wires.	Wiring configuration: Two power wires are run through the conduit carrying line voltage wires. The control wires are Class 2 and are not allowed in the same conduit. Some local codes require a separate Class 2 conduit.	Wiring configuration: Both power and control are routed through the same line-voltage wires. This ballast wires the same way as a conventional non-dim ballast.	Wiring configuration: All wires are Class 1, and relative to the phase control ballast, there is an additional control wire which is routed in the same conduit as the other wires.	Wiring configuration: No additional wires are required outside the fixture. The dimming device is either integral to the ballast or a separate interface within the fixture.
Typical applications: Small and open offices where users can control their own lighting; conference rooms and classrooms that require different lighting scenes for multiple types of use; supermarkets and certain retail spaces where merchandising and layout changes frequently.	Typical applications: Ideally suited for energy management systems. New construction and retrofit installations: auditoriums and training areas, conference rooms and boardrooms, department and specialty stores, education, healthcare, hotels, houses of worship, private and executive offices, restaurants.	Typical applications: While two-wire ballasts can be incorporated into building-wide control systems, according to their primary manufacturer they are ideally suited for architectural dimming, stand-alone, retrofit and low-cost projects. New construction and retrofit installations: auditoriums and training areas, conference rooms and boardrooms, department and specialty stores, education, healthcare, hotels, houses of worship, private and executive offices, restaurants.	Typical applications: Ideally suited for architectural dimming. Conference rooms, boardrooms, patient/examination/treatment rooms, houses of worship, theaters, convention areas, restaurants, air traffic control centers, industrial control rooms, partitioned meeting rooms, graphic art workstations, CAD/CAM workstations, private offices.	Typical applications: Ideally suited for spaces where individual control is desired without additional wiring. Conference rooms, board rooms, open and private offices.
Controlled by: Building automation system or lighting automation system. Occupant override through PC or local preset controller.	Controlled by: Energy management systems and occupants.	Controlled by: Local controls accessible to the occupants.	Controlled by: Central control systems and local controls accessible to the occupants.	Controlled by: Individual controls (infrared transmitters) given to the occupants.
Available from Advance, Lutron, OSRAM Sylvania, Tridonic, Universal.	Available from Advance, Lutron, OSRAM SYLVANIA, Tridonic, Universal.	Available from Advance, Lutron.	Available from Lutron.	Available from Lutron.
Bottom line: Installed component cost can be higher than comparable 0-10VDC systems due to power supply/router requirements, but the total installed cost can be significantly less after considering the wiring labor for group and scene control. Flexible system that offers individual ballast control and status feedback. Allows software configuration of lighting groups, presets matching the lighting to the space usage, and integrated energy management functions. May be configured as a large networked system requiring commissioning and training or as simple stand-alone room preset dimming controls requiring no special tools or PCs. Components of different manufacturers can be combined in the same installation.	Bottom line: Energy savings through building management system and occupant control.	Bottom line: Architectural dimming system, ideal for conference rooms, etc. as well as stand-alone and retrofits, and can be integrated into a buildingwide system.	Bottom line: Architectural dimming system that can be integrated into a buildingwide system.	Bottom line: Individual control system which can also be integrated into a buildingwide control system.

DIMMING ISSUES

Important issues related to dimming include perceived brightness, perception of light level reduction, power quality and energy consumption.

Perceived Brightness: As lamps are dimmed, light level decreases but the human eye may perceive a higher light level than is actually recorded by a light meter. This yields the "square law" curve, the theoretical relationship between measured light level and perceived brightness:

Perceived Light (%) = 100 x square root (Measured Light (%)/100)

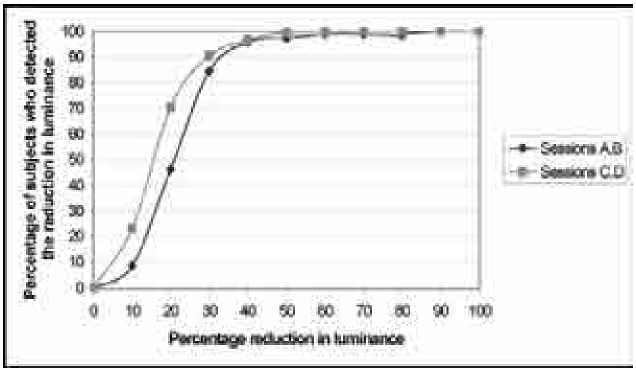
Consider this example (courtesy Lutron): At full brightness, the measured light level is 60fc. At the lowest dimmed level, 10% perceived light is desired:

- 1% measured light (0.6fcd) is perceived as 10% (desired result)
- 5% measured light (3fcd) is perceived as 22% (2x brighter than desired)
- 10% measured light (6fcd) is perceived as 32% (3x brighter than desired)

Perception of Light Level Reduction: A dimming issue for some applications is at what point in the change in light level will occupants notice the change.

The Lighting Research Center studied the relative threshold for detection of gradual reduction in light levels. Four sessions were conducted. Sessions A and B were conducted in a room with more than twice the light level of Sessions C and D.

The results are shown below:



Detection of slow light level reduction. Courtesy: Lighting Research Center.

The A, B curve shows:

- More than 90% of the population would not notice a 10% reduction in lumens
- About 75% would not notice a 15% reduction in lumens
- About 55% would not notice a 20% reduction in lumens

The Lighting Research Center concluded that since the subjects in the experiment were aware that the light level was about to change, which does not match real world conditions, the experiment results can be considered a maximum.

Power Quality: Total harmonic distortion (THD) has been reported to increase on 0-10VDC dimming ballasts as lamp output decreased (Specifier Reports: Dimming Electronic Ballasts, Lighting Research Center, October 1999).

Max. THD of less than 3% at full light output, for example, increased to a max. THD less than 25% at minimum light output. The increase in THD in turn decreased power factor – to a pronounced degree in some ballasts.

The Lighting Research Center concluded that since THD is a percentage of the fundamental current, a high THD at low fundamental current levels associated with low light output levels may not be a concern, as the actual distorted current is small.

Phase-control ballasts also experience THD, but the extent is unknown; in the 1999 Specifier Reports, Advance reported that their ballasts experienced less than 10% max. THD at full light output, but claimed that current THD and power factor at minimum light output depends on the control device used as well as the ballast.

Energy Consumption: Dimming ballasted lighting system may require higher wattage to operate than fixed light output systems, and do not experience an even lumens-to-wattage reduction. As an illustration, consider a fixed light output ballast powering two F32T8 lamps (see Table 2); the lighting system draws 65W of power.

A 0-10VDC ballast requires higher wattage to operate, and at 3% lamp output consumes 19% of the full input wattage. A phase-control ballast also requires higher wattage to operate, and at 5% lamp output consumes 22% of the full input wattage.

Note also that shorter lamps are less energy-efficient than longer lamps in dimming applications; each lamp has two electrodes that require the same amount of heating, but represent a larger percentage of the power consumption for the smaller wattage (shorter-length) lamp.

Table 2. Comparison of two 120V fixed light output (2) T8 lamp electronic ballasts from Advance Transformer with a 120V (2) T8 lamp 0-10VDC dimming ballast and a 120V (2) T8 lamp phase-control dimming ballast.

Lamps	Brand/Model	Voltage	Starting	Interface	Ballast Factor Max.	Min.	ANSI System Min. Watts	Max.
(2) F32T8	Centium ICN-2P32-SC	120V	Instant start	Fixed light output	0.88	NA	59	NA
(2) F32T8	Centium ICN-3P32-SC	120V	Instant start	Fixed light output	1.01	NA	65	NA
(2) F32T8	Mark 7 IZT-2S32-SC	120V	Programmed start	0-10VDC	1.00	0.03	68	13
(2) F32T8	Mark X REZ-2S32-SC	120V	Programmed start	Phase-control	1.00	0.05	68	15

DIMMING HID LAMPS - PART III

Craig DiLouie, Lighting Controls Association

High-intensity discharge (HID) lamp dimming has grown in popularity in recent years. Dimming HID lamps can result in energy savings, peak demand reduction and greater flexibility in multi-use spaces.

Dimming reduces energy costs by reducing the input power to the lighting system. It can be used to reduce peak demand and therefore reduce costly utility demand charges that can be a significant component of the total utility cost. And it offers greater flexibility to adapt spaces to different uses.

HID LAMPS

HID light sources, ranging from 20W to 2000W in size, can be found in numerous applications, from retail to industrial to public spaces. It is estimated that there are more than 105 million HID lamps in operation in the United States. HID lighting systems consume 12% of all lighting electricity consumed by the commercial sector, 31% in the industrial sector, and 87% in all outdoor stationary applications – an average of 17% of all electricity consumed by all lighting systems in the United States (see Table 1).

Table 1. Facts and estimates concerning HID usage in the U.S. Source: U.S. Lighting Market Characterization: National Lighting Inventory and Energy Consumption Estimate, Navigant Consulting, Inc./U.S. Department of Energy, September 2002.

	Commercial	Industrial	Outdoor Stationary	All (Including Residential)
Estimated number of HID lamps/U.S.	30.9 million	15.2 million	54.9 million	105.4 million
Average number of HID lamps/building	7	67	–	–
Operating hours/day	10.1	13.9	11.3	11
Distribution of HID lamps/sector	2%	5%	75%	2%
Distribution of installed wattage/sector	11%	30%	83%	7%
Distribution of electricity consumed/sector	12%	31%	87%	17%
Distribution of lamp output (Terralumens-hour or trillions of lumens/hour)	3,068	2,320	4,677	10,097

HID lamps are similarly constructed in that they feature an arc tube of stress- and heat-resistant material that contains gases, metals and the electrodes. They are identified via the predominant distinctive metals contained in the arc tube: high-pressure sodium (sodium), mercury (mercury) and metal halide (metallic halides).

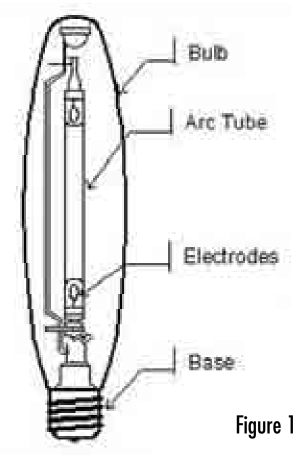


Figure 1. High pressure sodium lamp.

The arc tube is housed in a protective glass envelope. When starting voltage is applied to the electrodes from the ballast or ignitor, an arc is formed between them. Electrons in the arc stream collide with atoms of vaporized metals. The result of this action is the emission of light energy. Due to the high pressures of HID lamp operation, these wavelengths are concentrated in the visible light spectrum and therefore do not require a phosphor coating as a filter.

Of the three types of HID lighting, high-pressure sodium and metal halide are the most efficacious and offer the best color, limiting mercury's use. Metal halide offers superior color quality with a bright white light, while most high-pressure sodium offer the greatest efficiency at the expense of color with an orangish light.

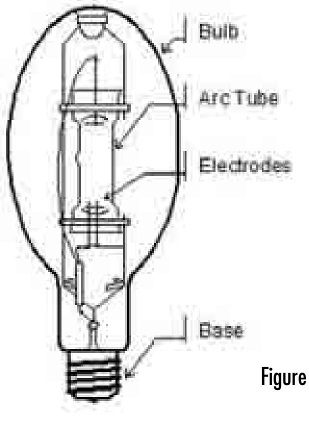


Figure 2. Metal halide lamp.

DIMMING STRATEGIES

Dimming can be employed in HID lighting systems to save energy, and enable the space to adapt to different uses, ambient conditions and time of day.

"HID dimming saves energy and thereby reduces owner operating costs," says A. J. Glaser, President of the Lighting Controls Association and Colorado-based HUNT Dimming. "It also maximizes end-user satisfaction by providing proper light levels."

Save energy: Dimming can be used to save energy during periods when the space is unoccupied but needs to stay lighted for safety and security reasons. Dimming can be achieved either manually via input from a switch or automatically via input from a control device. Automatic dimming can be set to respond to a preset schedule or variable ambient conditions such as occupancy and available daylight.

Occupancy. Dimming is a highly practical control method for saving energy with HID lighting systems to address periods of non-occupancy in spaces that must be constantly lighted.

High pressure sodium lamps can take 3-5 minutes to warm up; they take less than a minute to hot-restrike but don't reach full light for 3-4 minutes. Metal halide lamps take 2-10 minutes to warm up and 12-20 to hot-restrike, while pulse-start metal halide lamps take 1-2 minutes.

Given these characteristics, it is not practical to shut off and restart the lamps based on occupancy if the space must be made usable again quickly. In these situations, the lamps must be operated continuously, resulting in energy waste.

In addition, most lamp manufacturers rate HID lamp life at a minimum of 10 hours per start. Any reduction in burn time per start below this minimum will result in shorter lamp life.

If the lamps are dimmed instead in response to a signal from an occupancy sensor or time-programmable controller indicating the space is unoccupied, significant energy savings can occur during these periods, but the lamps will be able to achieve full light output quickly when the space becomes occupied again.

If occupation of the space is predictable, then timers or other time-programmable controllers may be used to deliver the control signal to dim the lamps. If occupation of the space is not predictable, then occupancy sensors may be used.

Daylight harvesting. Dimming can be used to adjust light levels based on available daylight via input from a photocell.

Peak demand reduction. Dimming can be scheduled using a time-programmable controller during times of peak demand, shaving the facility's peak demand and potentially reducing utility demand charges.

Flexibility: HID lighting systems are fixed output systems, but spaces may require different light levels because they are used for multiple purposes. Dimming makes the lighting system flexible and adaptive to different uses of the space.

A school gym, for example, can be dimmed to provide suitable lighting for sports, social events, maintenance and other uses. A wholesale outlet can be dimmed during maintenance and stocking operations. Spaces can also be dimmed to provide lighting for safety and security.

DIMMING TECHNOLOGIES

HID lamps can be dimmed using step-level or continuous-dimming systems.

Step-level dimming: Step-level dimming enables wattage reduction, usually at 100% and a step between 100% and 50% of rated power, causing step-level dimming systems to often be called two-level or bi-level dimming systems. However, some systems, often called tri-level dimming systems, can operate at three fixed light levels.

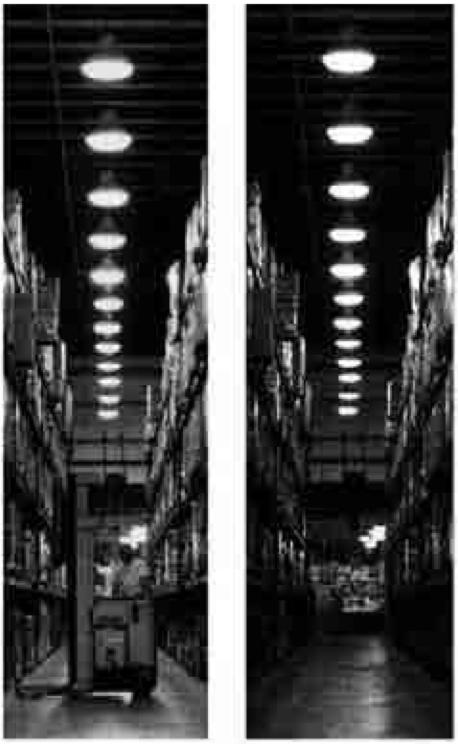


Figure 3. Step-dimming energy-saving application in a warehouse. When the space is occupied, the lamps are at full input power and light output (left). When the space is not occupied, an occupancy sensor sends a signal to the dimming system, which dims the lamps while reducing input power (right). Photo courtesy: Thomas Lighting, Inc.

This dimming method usually employs a constant-wattage autotransformer (CWA) magnetic ballast with one or two additional capacitors added to the circuit, depending on whether the ballast provides bi- or tri-level dimming. Relay switching of the capacitors results in additional impedance, which reduces the lamp current and the wattage. The capacitor circuit configuration may be a parallel or series connection.

Step-level dimming is achieved based on input from manual switches, scheduling devices, occupancy sensors and photocells. When the space is occupied, the lamp is brought from its reduced light output to about 80% of light output, followed by a brief warm-up time between 80% and 100% of light output.

Step-level dimming systems using the capacitive-switching method (magnetic dimming ballast) are generally less expensive than continuous dimming systems and are often more cost-effective than HID dimming panels for applications with relatively few fixtures. This type of dimming system also allows individual fixture control. It is suitable for retrofit; in addition, fixtures are available with a dedicated occupancy sensor and dimming ballast, suitable for direct fixture replacement.

Ideal applications for step-dimming include spaces that may be unoccupied for long periods of time but still need to be lighted, such as parking lots, warehouses, supermarkets and malls. High pressure sodium lamps are typically used for parking lots and warehouses, while metal halide lamps are typically used for supermarkets and malls. Step-level dimming systems work with all HID lamp types.

Depending on the lamp type and wattage, in a bi-level dimming system, the Low level may be 15-40% of light output and 30-60% of wattage. During dimming periods, therefore, energy savings as high as 40-70% can result.

A typical application for step-level dimming is a warehouse. When the space is unoccupied – as determined either by an occupancy sensor to detect variable occupancy, an operator with access to a high/low switch, or a timer or other scheduling system – the lamps are dimmed to an energy-saving level. Besides saving energy, the lower light level setting provides minimum lighting for safety and security. During periods of occupancy, the lamps are brought back to full light output.

In outdoor applications such as parking lots, an added bonus of dimming is a reduction in spill light that may impact adjacent properties.

Continuous (line-voltage) dimming: A number of technologies are available for smooth, continuous reduction of lamp wattage, including panel-level HID dimming and relatively new electronic HID ballasts. Ideal applications include anywhere it is advantageous to adapt the lighting system to a wide range of light levels to meet various space uses, such as airports, lobbies, classrooms, industrial facilities, sporting arenas, gymnasiums and auditoriums. With the exception of industrial buildings, metal halide lamps are typically used for most of these types of applications. Continuous dimming is also ideal for daylight harvesting by enabling the HID lamp output to be tuned to maintain a constant light level in the space.

Panel-level HID dimming. This method is used by control systems installed at the electrical panel that reduces the power supplied to the circuit. These control systems accept inputs from occupancy sensors, photocells and time-programmable systems.

The control system may be one of three types:

- Variable-step transformer: Variable-step transformers reduce the voltage supplied to the load, reducing light output and electrical input. They typically operate with existing CWA ballasts. They can reduce rated power down to 50%. While they have little impact on power quality, reducing voltage can affect lamp and ballast performance, according to the Lighting Research Center.
- Variable-reactor: This device keeps voltage constant but reduces current, enabling a reduction in rated power down to 30%.
- Waveform modification: Also called "wave choppers", these electronic control systems reduce the RMS voltage to the load to reduce rated power down to 50% by chopping a part of each voltage cycle. They are used for control of both HID and fluorescent magnetic systems. They are compact and light controls, but can reduce power quality as well as lamp and ballast performance, according to test conducted by the Lighting Research Center. Some devices reduce the light output almost immediately rather than a smooth, gradual reduction, which is perceptible to occupants.

Electronic HID ballasts. Electronic dimming ballasts for HID lamps are now available in new fixtures and provide continuous dimming, typically from 100-50% light output for metal halide and 100-30% light output for high pressure sodium lamps so as to preserve lamp life. In addition to dimming, they are designed to operate at a higher efficacy, improved color control, less stroboscopic effect, and harmonic distortion under 20%.

While generally not cost-effective for retrofit, electronic HID ballasts can yield significant energy savings in a new fixture. They are interoperable with occupancy sensors, photocells and time-programmable systems. The signal can be transmitted along the power circuit or low-voltage wires.

"The big trend is more control," says Glaser. "Sophistication in job design necessitates having the ability to vary the environment in precise increments and to exact levels. Continuous, variable control down to 50% provides this."

DIMMING CONTROLS

The dimming signal can be created using one of three types of controls:

- Manual, either local or remote switch
- Automatic, used in conjunction with occupancy sensors or photocells
- Time-programmable, either timers or scheduling systems

Dimming systems can be configured to control a single or multiple zones.

The occupancy sensor detects motion and sends a signal to the control system using the power line, low-voltage wire or fiber-optic cable.

RELATED ISSUES

There are a number of technical issues related to dimming HID lamps that lighting professionals should be aware of when specifying an HID dimming system. These issues relate to light output, efficacy, lumen depreciation, service life and color.

Efficacy: The ratio of reduction in wattage to reduction in light output is not proportional with panel-level and step-dimming control systems. Light output will be reduced further than the wattage reduction. In general, light output reductions are about 1.2-1.5 times the power reduction for metal halide lighting systems, and about 1.1-1.4 times the power reduction in high pressure sodium lighting systems. See Table 2 for changes in efficacy for a 400W coated metal halide lamp.

Table 2. Changes in efficacy for a 400W coated metal halide lamp. Efficacy is defined as the relative light output divided by relative system input power. Source: Lighting Research Center.

System Input Power (W)	Relative Efficacy (%)
439	100
393	91
354	82
302	79
260	67
247	59

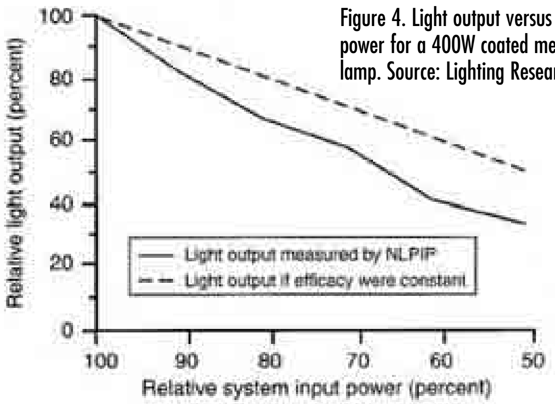


Figure 4. Light output versus system input power for a 400W coated metal halide lamp. Source: Lighting Research Center.

Dimming below 50%: When HID lamps are dimmed below 50% of rated power, they may experience degradation in service life, efficacy, color and lumen maintenance, or they may extinguish. Dimming below 50% of rated power, in fact, may reduce high pressure sodium and metal halide lamp life by 90%. As a result, dimming below 50% may void lamp warranties.

NEMA recommends that the maximum recommended dimming level is 50% rated lamp wattage for both metal halide and high pressure sodium lamps. NEMA further recommends that the lamps should be operated at full power for at least 15 minutes prior to dimming (unless the lamp is extinguished from a voltage interruption and the input voltage activates the timer, in which case 30 minutes is recommended before dimming.)

Compatibility: Some panel-level dimming systems are not compatible with electronic ballasts. Self-extinguishing lamps are not recommended for use with dimming systems. Some manufacturers recommend that metal halide lamps be operated base-up to preserve lamp life. Some panel-level dimming systems introduce harmonic currents into the electrical system.

Flicker: Dimming HID lamps, particularly high pressure sodium lamps, can make flicker more visible.

Color: HID lamps can experience a color shift during dimming and also a reduction in color rendering ability. Metal halide lamps are most susceptible to changes in lamp color characteristics.

Clear metal halide lamps, for example, will shift to a higher color temperature or cooler appearance during dimming, from white to blue-green. When a clear metal halide lamp is dimmed to 50% of rated power, color temperature can increase 1500K, according to the Lighting Research Center.

Color rendering may also be affected; when a clear metal halide lamp is dimmed to 50% of rated power, the Color Rendering Index (CRI) value may decline from 65 to 45.

Coated metal halide lamps experience a much smaller shift and a smaller reduction in CRI than clear lamps.

High pressure sodium lamps can also be affected, typically experiencing a 50-200K reduction in color temperature when they are dimmed, appearing more yellow, while CRI experiences a minimal change.

ALTERNATIVE SOLUTIONS

Facility owners and operators can achieve energy savings with HID lighting without dimming, by considering power reducers, low-wattage HID lamps, and low-bay fluorescent T5 lighting systems.

Power reducers: Power reducers, or current limiters, are retrofit devices that can be wired to control an HID ballast or can be installed at the electrical panel to control an entire HID circuit. They are typically designed to work with common CWA ballasts and lamps at least 175W in size. Ideal for overlighted spaces where variable light levels are not needed, they can achieve a preset reduction of 20-25% rated power and may extend ballast life by reducing ballast case operating temperature. Reduced-wattage and lower output HID lamps can also be used to retrofit existing fixtures in such applications, as an alternative to power reducers. Although power reducer manufacturers claim that their devices result in little or no reduction in perceived light output, light output will, in fact, be reduced. It is recommended that lighting professionals conduct a trial installation and measure light levels and wattage before and after installation of the given power reducer.

Fluorescent T5 or T5HO systems: T5HO lamps have been incorporated into a new type of low-bay (>15 ft.) fixture. This 4- or 6-lamp, instant-on/restrike, high-lumen-maintenance, high-CRI, 20,000- or 28,440-lumen fluorescent fixture has become a popular energy-saving alternative to metal halide in industrial facilities, warehouses, gymnasiums, etc. All things being equal, the T5HO fluorescent is more efficient than metal halide, provides better color rendering and consistency, and has instant-on and instant-restrike, with the tradeoff that more lamps and fixtures would be required to light the space, and the fluorescent lamps may not perform as well in cold environments. An interesting side benefit of T5 low-bays is that they can double for emergency lighting.

LATEST SOLUTIONS

Below are several of the latest HID dimming solutions offered by members of the Lighting Controls Association.

Advance Transformer: Advance Transformer recently introduced Dynavision, a new microprocessor-based electronic ballast for the operation of pulse-start metal halide lamps. Because of DynaVision's ability to maximize lamp lumen maintenance over life, a variety of cost saving opportunities is possible through energy savings and reduced re-lamping and maintenance. In a scenario where the number of fixtures is unchanged, a DynaVision ballasted 320W lamp could be substituted to produce lumen levels at or above those provided by a 400W probe-start system.The result is a substantial reduction in watts per square foot.

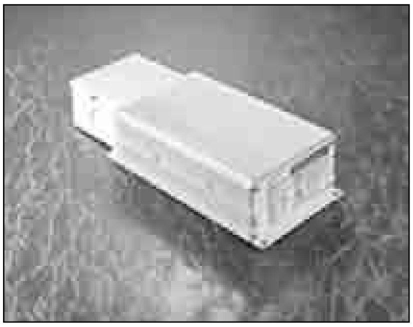


Figure 5. Dynavision from Advance Transformer.

Alternatively, energy savings can be achieved with DynaVision by reducing the number of fixtures utilized, thanks to the ballasts' ability to maintain lumen levels over lamp life. A DynaVision ballast will operate either a 320W, 350W or 400W pulse-start metal halide lamp, from any manufacturer, at its rated wattage level. DynaVision ballasts also feature Advance IntelliVolt technology, permitting operation on different voltage systems, ranging from 200V to 277V.

Other important DynaVision features include continuous 0-10V dimming, down to 50% of lamp power, and the ability to directly control a quartz auxiliary lamp up to 250W.

HUNT Dimming offers the Simplicity Series Digital Dimming Systems, designed to simplify contractor installation by utilizing a compact, lightweight design and minimal wiring requirements, and also designed to maximize owner benefits with simplified programming and ease of use.

Figure 6. Simplicity Series Digital Dimming Systems from HUNT Dimming.

The Simplicity Series wall-mounted control stations include LCD touchscreens which provide visual and intuitive digital lighting control for single location operation, monitoring and programming of all lighting zones; pushbutton control stations which provide flexibility and control through pre-programmed and field changeable functions; and, handheld infrared remote controls.

The Simplicity Series Digital Dimming Panels contain 12 individually addressable outputs. Each circuit is rated at 20A and is capable of being dimmed or switched. As few as four and as many as 12 power modules can be provided per dimming panel. Each dimming module is multi-rated to control incandescent, fluorescent (phase-control), low voltage (electronic or magnetic), neon, cold-cathode, fan-speed and non-dim (or switched) sources. The products are UL and cUL Listed.

These digital dimming systems can be used with 0-10VDC dimmable HID products such as Dynavision from Advance Transformer.

The Watt Stopper: The Watt Stopper offers the DM-100 and DM-105 bi-level HID controllers.

The DM-105 and DM-100 are control modules that switch HID lighting based on occupancy or other control signals. By providing bi-level (high/low) control, they eliminate the restrike time problem associated with on/off control of HID lighting. This enables a significant source of energy savings, potentially up to 50%.

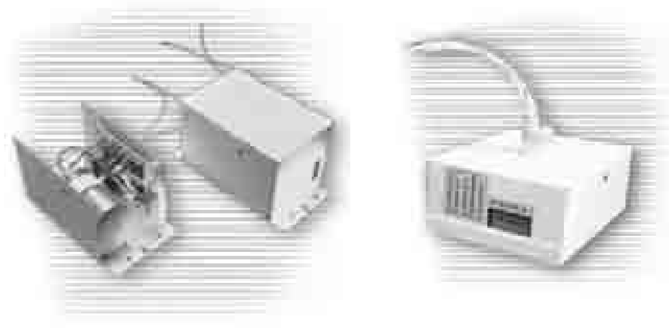


Figure 7. DM-105 and DM-100 bi-level HID controllers from The Watt Stopper

Both controllers are designed to operate 175-1000W HID lamps operated on CWA-type ballasts. The DM-105 installs on new or existing fixtures and requires a bi-level capacitor which is installed inside the fixture. It requires four wires. The DM-100 mounts directly onto the HID fixture or at a remote location using two wires. Both work with a 24VDC controlling device, such as an occupancy sensor, photocell or time switch, and switches HID lighting between high and low. Both utilize a dual capacitor and capacitor switching to achieve bi-level control. Multiple modules can be linked together and then be controlled from one device.

ULTRAWATT: ULTRAWATT’s PowerGate Intelligent Lighting Management System (PGi) offers digital panel-level HID dimming. The PGi system features a custom cabinet design connected to existing lighting circuit breakers and is ideally suited for retrofit applications. Control cards can be accessed, from either local or remote location, through proprietary PC-based software for fine-tuning the lighting system according to time, occupancy, or utility requirements. Analysis of the system’s operations can also be used in conjunction with facility maintenance programs.

INTRODUCTION TO LIGHTING AUTOMATION - PART IV

Lighting controls play a critical role in electric lighting systems, providing the function of:

- Turning the lights on and off using a switch; and/or
- Adjusting light output up and down using a dimmer

In recent decades, technological development has increasingly automated these functions and allowed integration of devices into larger, more flexible systems. The result is significantly expanding energy-saving opportunities, flexibility, reliability and interoperability between devices from different manufacturers.

One thing remains the same: A good lighting design includes a good controls design. The goal of an effective control system is to support lighting application goals, which often translates to eliminating energy waste while providing a productive visual environment.

THE LIGHTING CONTROL SYSTEM

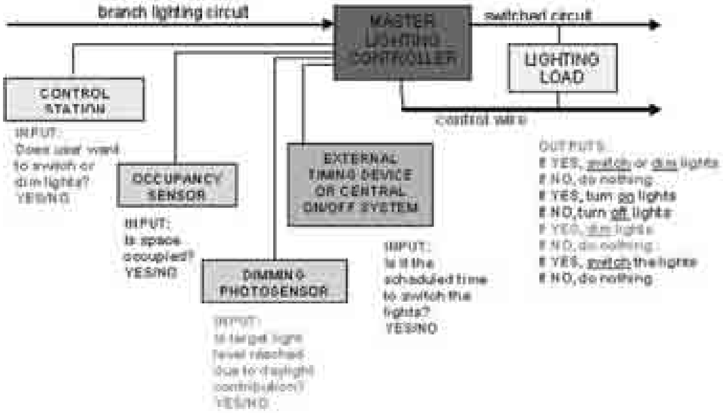
Lighting control systems contain three components linked by communication wiring, which is used to transmit control signals, and power wiring, which supplies power.

Component	Sensing Device'	Logic Circuit'	Power Controller
Function	Provides information to logic circuit	Decides whether to supply lighting, and how much	Changes the output of the lighting system

We can therefore view a lighting control system or device as an apparatus that 1) receives information, 2) decides what to do with that information, and 3) changes the operation of the lighting system. In other words, we can look at lighting control devices based on inputs and outputs. Below are three examples.

Control	Input	Decision-making	Output
Occupancy sensor	Sensor detects presence or absence or people	Decide whether to turn on or shut off lights	Sends signal to relay, which closes or opens circuit
Control station and dimming panel	User presses button to recall preset scene	Control station recalls scene from memory and sends signal to dimmer at dimming panel	Dimmer adjusts light output to desired level
Dimmable ballast	Controller provides signal to dim	Ballast is instructed to dim, and by how much	Ballast alters the current to the lamps, dimming them

Below is an example of a robust lighting control system with a control station, occupancy sensor, photosensor and time switch or centralized switching system providing a variety of inputs to the master lighting controller. The lighting controller can be a switching panel, dimming panel or both linked together. The controller, in turn, controls the lighting load with a variety of outputs based on decisions made by the logic circuits. Since different control strategies may have overlapping device requirements, control synergies can be gained by building a system of simple components.


branch lighting circuit
MASTER LIGHTING CONTROLLER
switched circuit
LIGHTING LOAD
control wire
CONTROL STATION
INPUT: Does user want to switch or dim lights? YES/NO
OCCUPANCY SENSOR
INPUT: Is space occupied? YES/NO
EXTERNAL TIMING DEVICE OR CENTRAL ON/OFF SYSTEM
INPUT: Is it the scheduled time to switch the lights? YES/NO
DIMMING PHOTOSENSOR
INPUT: Is target light level reached due to daylight contribution? YES/NO
OUTPUTS:
If YES, switch or dim lights
If NO, do nothing
If YES, turn on lights
If NO, turn off lights
If YES, dim lights
If NO, do nothing
If YES, switch the lights
If NO, do nothing

PURPOSE OF LIGHTING CONTROLS

In many applications, the overall purpose of the lighting control system is to eliminate waste while providing a productive visual environment. This entails:

- Providing the right amount of light
- Providing that light where it's needed
- Providing that light when it's needed

THE RIGHT AMOUNT OF LIGHT...

Control systems provide the right amount of light. This lighting decision is based on the type of tasks being performed in the space. Lighting controls support this goal in two ways.

Lighting controls provide flexibility in adapting the lighting system to different uses. For example, a school auditorium, which is home to a diverse range of activities, would need different light levels for these activities.

Photo courtesy of Lutron Electronics.

Lighting controls provide the ability for users to adjust light levels based on changing needs or individual preference, either through dimming or through bi- or multi-level switching. Dimming provides the greatest amount of flexibility in light level adjustment.

By enabling the lighting system to deliver the right amount of light to the task, the control system can eliminate energy waste while providing a productive visual environment.

...WHERE IT'S NEEDED...

Lighting controls support the lighting system putting light where it's needed. This entails establishing control zones, which is a light fixture or group of fixtures controlled simultaneously as a single entity by a single controller. Zones are typically established based on types of tasks to be lighted, lighting schedules, types of lighting systems, architectural finishes/furnishings, and daylight availability.

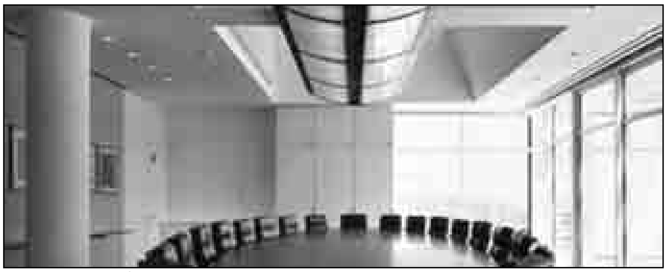


Photo courtesy of Lutron Electronics.

The greater the resolution of the control zones – that is, the smaller they are – the greater the precision the control system can provide. For example, a control system can turn the lights on automatically when a person enters a building during non-operating hours. Only the areas to be used should be lighted, however, and not the entire floor. A zone can also be as small as single ballast or light fixture, which enables the greatest amount of control resolution. For example, each user in an open office can be given capability via PC or handheld remote to dim his or her own lighting to personal preference.

Generally, the smaller the control zone, the greater the control resolution and potential utility cost savings and the greater the opportunity to enable the lighting system to support visual needs.

...AND WHEN IT'S NEEDED.

An effective control system ensures that the lighting system operates – and consumes energy which costs the owner money – only when it's needed. Determining when the lighting system should be operating depends on how the space is occupied. This will entail whether a time-based or a threshold event should be the deciding factor in whether the lights should be turned on or shut off.

If occupancy is predictable, a time-based strategy can be considered. For example, a switching system can be scheduled to automatically shut off the lights by area, by floor or in an entire building if a building's occupancy is predictable.

Photo courtesy of Leviton

If occupancy is not predictable, a threshold-event-based strategy can be considered. For example, occupancy sensors can be used to automatically turn on and shut off lights in areas depending on whether the sensor detects the presence or absence of people in the monitored area.

By ensuring the lighting system provides light only when it's needed, the control system can significantly reduce wasted energy and generate utility cost savings for the owner.

ENERGY MANAGEMENT

Advanced lighting control devices and systems can be used to reduce ongoing costs for the owner and thereby increase profitability and competitiveness. According to the New Buildings Institute, lighting controls can reduce lighting energy consumption by 50% in existing buildings and by at least 35% in new construction.

- **Lighting energy:** Controls can reduce the amount of power drawn by the lighting system during operation and also the number of operating hours, thereby reducing utility energy charges.
- **Lighting demand:** Controls can reduce the amount of power drawn by the lighting system, reducing utility demand charges – particularly during peak demand periods, when demand charges are highest.

These cost savings can produce a short payback and a high rate of return for the investment in the new controls. In new construction, the rate of return is often higher because only the premium, not the total installed cost, will be recouped before positive cash flow is realized.

VISUAL NEEDS

The project may be driven by business benefits other than energy savings by providing increased performance and flexibility:

- Adapt the lighting for multiple uses of a space, such as a conference room or gymnasium.
- Adapt the lighting to evolving space needs resulting from employee churn and office strategies such as hoteling and hot-desking.
- Mood-setting for restaurants and similar applications.
- Increasing worker satisfaction by providing personal control of their lighting systems in office and other environments.
- Enhanced aesthetics and image, greater space marketability, and pollution prevention.

These business benefits are often more difficult to calculate than energy savings, but tangibly contribute to the bottom line.

Studies, for example, have shown that personal lighting control can increase worker satisfaction, a major contributor to productivity, while providing energy savings. According to the Building Owners and Managers Association (BOMA), energy costs run about $2/sq.ft. in a typical commercial building while worker salaries and benefits can run to $130/sq.ft. or more. While reducing energy costs by a large percentage can be profitable, increasing productivity by even a very small percentage can be much more profitable.

ENERGY CODES

Lighting automation is now mandated in most of the United States. With the adoption of the ASHRAE/IES 90.1-1999 model energy code by the U.S. Department of Energy as the minimum national standard, a majority of state energy codes require automatic shut-off of all lighting in commercial buildings greater than 5,000 sq.ft. in size, with few exceptions. Automatic shut-off can be provided by occupancy sensors and programmable time scheduling devices. Some codes, such as California's Title 24, are even stricter. The 2005 Title 24 enacted in October 2005, for example, requires daylighting controls in some spaces as well as commissioning for control systems.

DETERMINING A LIGHTING CONTROL STRATEGY

The questions below can help narrow down selection of an appropriate control strategy:

- What are the load and space characteristics?
- What are the project goals for the lighting system?
- What is required by energy, building and electrical codes?
- Should the load be switched or dimmed?
- What degree of automation is required?
- Should the lighting system be controlled locally, from a central location, or both?
- What degree of control accuracy is required?
- What is the target value level – the balance between performance and cost?

WHAT ARE THE APPLICATION GOALS?

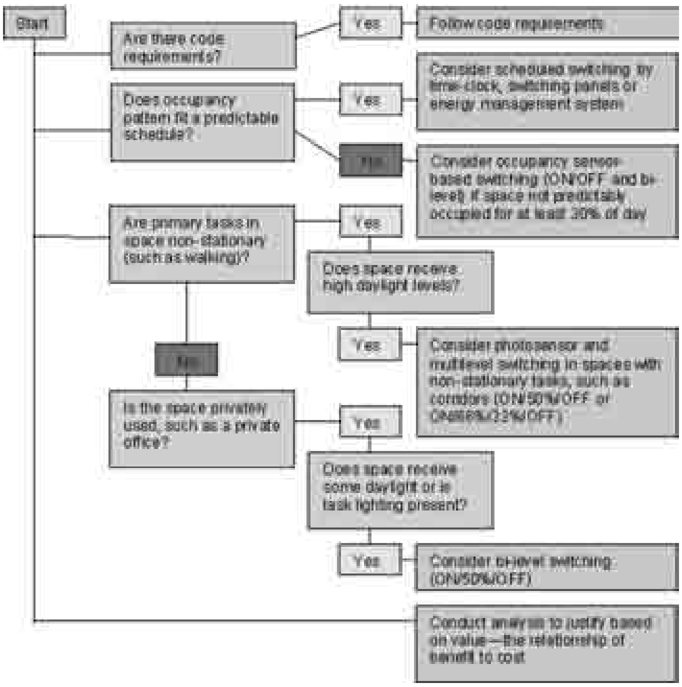
	2003 Ducker Research/ Watt Stopper Lighting Automation Study	**2004-2005 ZING Communications/ LCA Dimming Study**	**2005 Square D Bulls Eye Study**
Methodology	Telephone interviews of 158 facility managers, electrical engineers and architects	Email survey to 4,317 lighting designers architects, engineers, distributors and contractors with 6.7% response	Direct mail survey
Study Focus	Automatic Switching	Dimming	Lighting Controls
Research Question	What are the top five factors driving the use of automatic lighting controls?	What are the top five reasons for specifying dimming systems?	What are the most important benefits of lighting control?
Average Respondent Answer	1. Increasing energy savings	1. Ability to light space for different uses (flexibility)	1. Reduce energy costs
	2. Complying with owner requests	2. Client request	2. Worker safety
	3. Compliance with state and national energy codes	3. Energy savings	3. Occupant convenience
	4. Providing occupant control capability	4. Add value to the design	4. Prolong equipment life
	5. Obtaining utility rebates and incentives	5. Mood setting	5. Meet state energy codes

SWITCHING OR DIMMING?

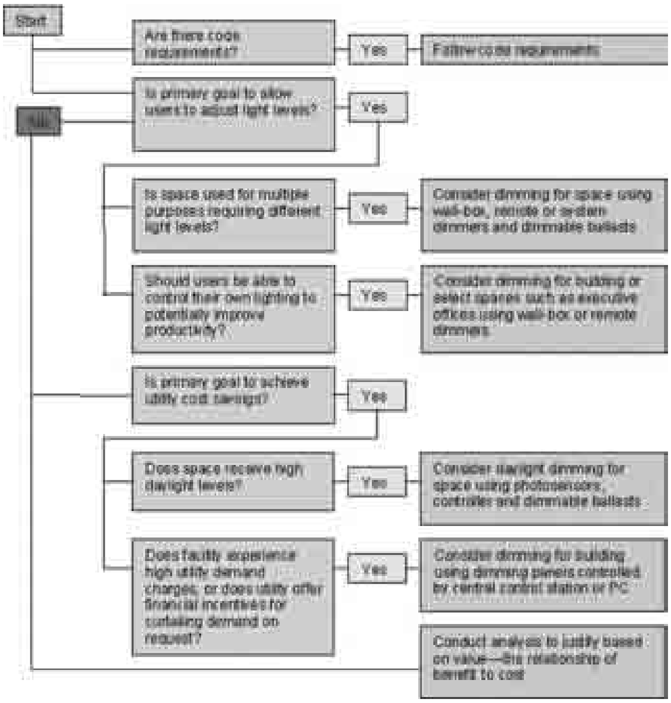
The first primary decision after defining the load and the application goals is whether to switch or dim the load. Switching and dimming are stand-alone strategies but are often used in the same facility, and may be integrated in the same control system.

Method	**Switching**	**Dimming**
Primary Use	Energy management	Visual needs
Basic Function	Turn lights on or off	Change light output with smooth transitions between light levels
Benefits	Utility cost savings	Occupant satisfaction, flexibility, utility cost savings
Advantages	Relatively inexpensive and simple to commission	Can set light output at any level within available range, greater user acceptance due to smooth transitions between light levels
Disadvantages	Lower user acceptance in occupied spaces with stationary tasks due to abrupt, noticeable changes in light level	Higher installed cost, and can require more sophisticated commissioning

WHEN TO SWITCH


Start
Are there code requirements?
Yes
Follow code requirements
Does occupancy pattern fit a predictable schedule?
Yes
Consider scheduled switching by time-clock, switching panels or energy management system
No
Consider occupancy sensor-based switching (ON/OFF and bi-level) if space not predictably occupied for at least 30% of day
Are primary tasks in space non-stationary (such as walking)?
Yes
Does space receive high daylight levels?
Yes
Consider photosensor and multilevel switching in spaces with non-stationary tasks, such as corridors (ON/50%/OFF or ON/66%/33%/OFF)
No
Is the space privately used, such as a private office?
Yes
Does space receive some daylight or is task lighting present?
Yes
Consider bi-level switching (ON/50%/OFF)
Conduct analysis to justify based on value—the relationship of benefit to cost

WHEN TO DIM


Start
Are there code requirements?
Yes
Follow code requirements
Is primary goal to allow users to adjust light levels?
No
Yes
Is space used for multiple purposes requiring different light levels?
Yes
Consider dimming for space using wall-box, remote or system dimmers and dimmable ballasts
Should users be able to control their own lighting to potentially improve productivity?
Yes
Consider dimming for building or select spaces such as executive offices using wall-box or remote dimmers
Is primary goal to achieve utility cost savings?
Yes
Does space receive high daylight levels?
Yes
Consider daylight dimming for space using photosensors, controller and dimmable ballasts
Does facility experience high utility demand charges, or does utility offer financial incentives for curtailing demand on request?
Yes
Consider dimming for building using dimming panels controlled by central control station or PC
Conduct analysis to justify based on value—the relationship of benefit to cost

LOCAL OR CENTRAL CONTROL?

<table>
<tr><th colspan="2">CONTROL METHOD</th></tr>
<tr><td colspan="2">Divide the building into series of control zones, each zone constituting a lighting load controlled by a single controller</td></tr>
<tr><th>Localized</th><th>Centralized</th></tr>
<tr><td>Each zone operated by its own point of control independently of other zones</td><td>All zones operated by single point of control</td></tr>
<tr><td>Lower cost, less sophisticated commissioning</td><td>Greater capabilities, flexibility, potential cost savings</td></tr>
<tr><td colspan="2">The control scheme can be designed with local systems and a centralized system working together as layers. Both local and centralized systems can be integrated into building automation systems for control of lighting and HVAC.</td></tr>
</table>

WHAT DEGREE OF AUTOMATION IS REQUIRED?

Manual lighting controls range from a single switch to a bank of switches and dimmers that are actuated by toggles, rotary knobs, push buttons, remote control, and other means. Manual controls can be cost-effective options for small-scale situations. However, as the size of the lighting system grows, manual controls lose their cost-effectiveness. In addition, manual controls often waste energy because the decision to shut off the lights when they are not needed is based entirely on human initiative.

Method	Strategy	Manual vs. Automatic
Switching	Occupancy sensors	Turn the lights on or off automatically based on whether space is occupied
	Scheduled automatic shut-off at end of workday switching panels, time-clocks or building automation system	Turn selected lights on or off automatically based on schedule when space is predictably unoccupied
	Scheduled automatic shut-off of select loads (bi-level switching) during peak demand periods, time-clocks or building automation system	Turn off one or two lamps in each fixture or checker board fixtures automatically for load shedding during peak demand periods
	Bi-level switching using wall switches controlling lighting system layered as two separate circuits	Turn selected circuit on and off manually to achieve ON, 50% light level, and OFF
	Multilevel switching using photosensor and low-voltage relay	Turn the lights off automatically based on available ambient daylight
Dimming	Dimming control of smaller loads using wall-box and remote dimmers	Adjust light output manually based on space need or personal preference
	Dimming control of larger loads using control stations and dimming panels	Adjust light output manually based on space need or personal preference
	Daylight harvesting using photosensor, controller and dimmable ballast	Adjust light output automatically to maintain target level as daylight enters space
	Adaptive compensation using dimming panels and scheduling device such as time-clock	Adjust light output automatically to provide lower light levels at night based on studies about human lighting preferences
	Peak shaving and load shedding using dimming panels and scheduling or control device	Adjust light output automatically during peak demand periods and/or manuallybased on utility request to curtail load

STRATEGIES

Occupancy sensors

Dimming		▨	Switching
Local	▨		Centralized
Manual		▨	Automatic

Scheduling (automatic shut-off)

Dimming		▨	Switching
Local		▨	Centralized
Manual		▨	Automatic

Bi-Level/Multilevel switching

Dimming		▨	Switching
Local	▨		Centralized
Manual	▨	▨	Automatic

Task Tuning (Personal Dimming)

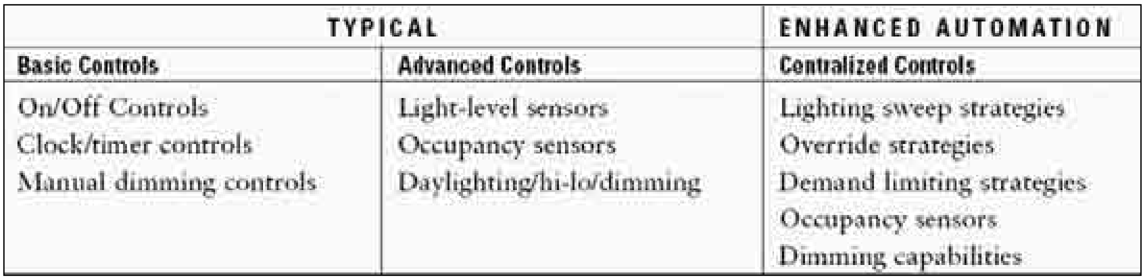
Dimming	▨		Switching
Local	▨		Centralized
Manual	▨		Automatic

Daylight Dimming

Dimming	▨		Switching
Local	▨		Centralized
Manual		▨	Automatic

Scheduled Dimming

Dimming	▨		Switching
Local		▨	Centralized
Manual		▨	Automatic

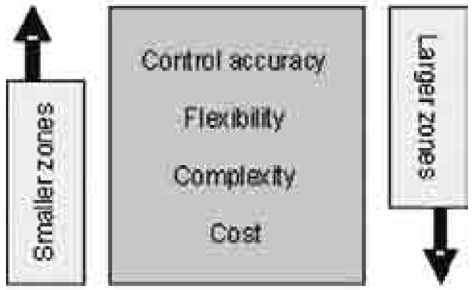


TYPICAL		ENHANCED AUTOMATION
Basic Controls	**Advanced Controls**	**Centralized Controls**
On/Off Controls	Light-level sensors	Lighting sweep strategies
Clock/timer controls	Occupancy sensors	Override strategies
Manual dimming controls	Daylighting/hi-lo/dimming	Demand limiting strategies
		Occupancy sensors
		Dimming capabilities

Above graphic courtesy of California Energy Commission.

WHAT DEGREE OF CONTROL ACCURACY IS REQUIRED?

A key step in designing a lighting control system is to determine the degree of control over the lighting system, which means breaking the load up into zones. Establishing smaller zones increases control accuracy and flexibility but also increases cost.



FINAL WORD

By determining the most appropriate control strategy for the application using these simple guidelines, one can specify control systems that provide the right amount of light where it's needed, and when it's needed – thereby minimizing optimizing operating costs and user satisfaction.

CONVENTIONAL LIGHTING: BASIC HOME TROUBLESHOOTING AND REPAIRS

Don Vandervort

LIGHT DOESN'T WORK

When a single light doesn't work, the problem is almost always the bulb, the circuit breaker (or fuse), or the switch. The first and most obvious solution is to replace the bulb with a good one and, if that doesn't work, track down the problem through a process of elimination.

1) Test the bulb and, if necessary, change it. Be sure the bulb is screwed into the socket all of the way. If you put a new bulb in the socket and it still doesn't work, check the new bulb in a working socket to be sure it isn't defective.
2) Remove the bulb. Turn the light switch on, and check to see if the socket is receiving power by touching the two leads of a voltage tester so that one touches the brass contact at the center of the socket and the other touches the threaded metal bulb housing. If you get a reading of current, try another bulb. If you don't, go on to the next step.
3) Be sure that the circuit breaker (or fuse) for the non-working fixture has not tripped. If it has, reset the breaker or replace the fuse, and try the light again.
4) If it still doesn't work, turn off the circuit breaker that serves the non-working fixture, unscrew the cover plate from the light switch, and use a voltage tester to be sure none of the wires in the electrical box are still "hot". Then be sure the wires are securely fastened to the switch's terminals.
5) Put the cover plate back on, turn the circuit back on, and try the switch again. If it doesn't work, go on to the next step.
6) Turn the circuit back off, remove the cover plate, remove the switch and, using a multi-meter or a continuity tester, check the switch.
7) If the switch is defective, replace it with one that has the same amperage and voltage ratings. (Because switches are quite inexpensive, it isn't worth the effort to attempt repair.)
8) If the switch tests fine, remove the cover plate from the light fixture, use a voltage tester to be sure there are no hot (charged) wires in the electrical box, then repair or replace the light fixture.

To test a lamp socket, you'll need a continuity tester, and you'll need to remove the socket from the lamp frame. Unplug the lamp, and remove the shade, the light bulb, and the harp (or frame) that supports the shade. Squeeze the socket's outer shell at the base and gently work it off. Then slip off the insulating sleeve.

Clip the continuity tester wire to one plug blade and touch the probe to the silver screw on the socket. Then touch it to the brass screw. Clip the wire to the other plug blade and touch the probe to the silver screw on the socket. Then touch it to the brass screw. The tester should light with at least one combination in either case. If not, the cord is your problem and you'll need to replace it.

To test the socket, clip the tester wire to the threaded collar and touch the probe to the brass screw. Turn or click the lamp's on-and-off switch. The tester should also go on and off. If not, the socket is your problem, and you'll need to replace it.

A continuity tester is very helpful for checking to see whether an electrical circuit is complete or broken.

HOW TO CHECK A STANDARD LIGHT SWITCH

From time to time wall switches fail when the contact points within the switch become worn or have eroded. It's easier and cheaper to replace a switch than it is to repair it. Be aware that you don't need to replace it with the same kind of switch. For example, you might want to replace a single-pole switch with a dimmer switch to save energy and vary the lighting in a room to suit your needs. You can't, however, simply replace one switch with another type that requires more wires – a single-pole switch with a three-way switch or sophisticated lighting controls, for example.

When you replace a switch, make sure you check the amp and voltage ratings on the back of the old switch. The new switch should have the same ratings as the old.

WHAT TO LOOK FOR

If you have aluminum wiring (the metal part of wires look silvery), be sure to get a replacement switch marked CO/ALR. Unmarked or CU/AL switches should be replaced with CO/ALR switches.

If a light doesn't work and you suspect the switch:

1) Turn off the power to the light circuit.
2) Remove the switch's cover plate and unscrew the two screws that mount the switch to electrical box.
3) Use a voltage tester to check the screw terminals on the side of the switch to make sure they're not hot (charged), then gently pull the switch out from the box.
4) Unscrew the wires from the two terminals and straighten their ends with a pair of pliers.
5) Twist the two bare ends together and screw a wire nut onto the twisted pair.
6) Turn the circuit back on. If the light goes on, the switch is bad – just buy a new one and re-install it.

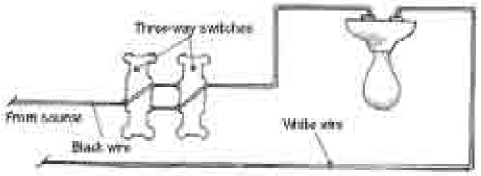
Remember to turn the power back on first! If the light still doesn't work, the problem is in the wiring or the light fixture, so turn off the power to the circuit, reconnect the original switch, put the cover plate back on, restore the power to the circuit, and check the light fixture (above) or call an electrician.

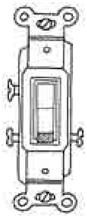
ABOUT THREE-WAY SWITCHES

When replacing a three-way switch (one that allows you to control one or more fixtures from two different places, such as from opposite ends of a hallway), be sure to return the wires to the proper screw terminals. On three-way switches, two terminals are the same color and the third terminal – called the common terminal – is a different metal or color. Put a piece of tape on the wire that goes to the common terminal screw. The other two wires can attach to either of the identical terminals.

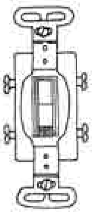
THREE-WAY AND FOUR-WAY SWITCHES:

Two three-way switches are used where you want to be able to turn a light off or on from two locations, such as at each end of a hallway or stair.





A three-way switch (left) has three terminal screws, may have a green grounding screw and has and no “On” or “Off” markings on the toggle.



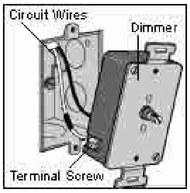
A four-way switch (right) has four terminals, may have a green grounding screw and has no markings on the toggle. It’s combined with three-way switches to control lights from three or more different locations.

DIMMER MAKES LIGHT BUZZ

A dimmer switch can cause a light bulb’s filament to vibrate, making a buzzing sound when its on a less-than-full setting. You can buy a new dimmer that’s designed not to buzz and replace it, but before you do, try replacing the bulb with a “long life” light bulb that has a sturdier filament and is rated at 130-volts instead of the far more common 120-volts.

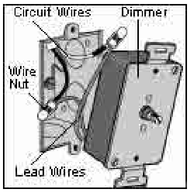
HOW TO INSTALL A DIMMER

Changing a single-pole switch to a dimmer switch is easy. Both are wired into hot wires only and have either terminal screws or lead wires. Be sure to shut off the power at the circuit breaker and test with a circuit tester to be sure it’s off. Once you’ve removed the switch from the electrical box, test bare wire ends again to make sure they’re not active.



Remove the old switch and disconnect the wires. If the new switch has a terminal screw, loop the circuit wires clockwise around the terminal screws.

If the new dimmer has short wires coming out of its body, connect the bare ends to the wires in the wall and secure with wire nuts. Push the wires and dimmer into the wall box, secure it with the two screws at top and bottom, and put a faceplate over the top.



LIGHTING DIMMER SWITCHES

The most familiar enhanced-control device, the dimmer lets you lower or raise light levels so that they’re appropriate to the need. For example, a bathroom dimmer can be set low for restful light when bathing or nighttime lighting, then raised to higher intensity when you need to put on makeup. In a child’s bedroom, a dimmer can provide low-level light at night for reassurance or for a parent’s nighttime checks, then fill the room with light for daytime play. Likewise, a family room can be lit with low-level lighting for relaxed entertaining, then perked up with full lighting for family activities.

Most dimmers today are solid-state devices. They actually switch off and on very rapidly – 120 times per second. Because the human eye perceives the overall light emitted, the brightness of light delivered is actually a product of how long the current is in the “off” and “on” cycles.

Dimmers save money two ways. First, they significantly cut wasted energy by using only the amount of electricity needed. When a light is dimmed by 25%, a dimmer saves about 20% of the electricity required. When dimmed by 50%, it saves 40% of the electricity. Second, a dimmer greatly extends lamp (bulb) life because it reduces strain on the filament. When dimmed by 25%, a lamp lasts 4 times as long as it would at full power, and dimmed by 50%, it will last as much as 20 times longer.

No special wiring is needed for a dimmer – it may replace any conventional light switch, but you must buy specially-rated dimmers for fluorescent or low-voltage lighting and fans. Any dimmer you buy should be rated to handle the type and total load of fixtures it will control.

Dimmers may be operated with a toggle, a dial, a slide, a paddle switch, a touch-pad or electronic button; some types integrate two or more of these methods to handle different tasks. When buying one, whether to choose a toggle, rotary dial or slide switch is really a matter of personal preference; focus instead on the range of control and the features. Does it offer full-range dimming? Can it be preset to specific light levels? How many levels? Is it easy to use?

Of course, the more features a dimmer has, the more expensive it generally will be. The idea is to figure out how it will be used, then tailor your choice to the need. For example, for general dimming applications you might want to choose a multi-function dimmer like Lutron’s Maestro, which has a touch-switch control that will recall a preset light level if you touch it once or turn the lights all of the way on if you touch it twice. Small LEDs along one edge show the level of light and it can be adjusted to fade to off very slowly so you have time to leave the room.

RECESSED LIGHTS GO OFF AND ON

To minimize the risk of fire, recessed lights have a thermal protector that shuts them off when they get too hot. Be sure the bulb doesn’t exceed the maximum wattage indicated inside the metal housing. And check whether a reflector-type bulb is required. If the bulb is the proper size and type, loosen the wing nuts or screws that adjust the bulb-holder’s position inside the metal housing and slide the bulb unit down a little, then re-tighten. If possible, be sure insulation inside the ceiling is held back away from the fixture at least 3 inches. A flicker or spark indicates faulty wiring or a defective switch. If you’re competent at handling electrical problems, shut off the power to the circuit and check wire connections at the switch and fixture. Otherwise, call an electrician.

LIGHTS DIM WHEN APPLIANCES KICK ON

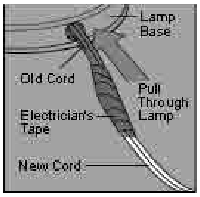
Too many electrical devices are drawing power from one circuit. If plugging some devices into receptacles on other circuits doesn't solve the problem, you may have to upgrade your home's electrical service panel.

For today's electrical needs, a main electrical panel should deliver 100 amps of power or more; 150 or 200-amp services are even better for homes fitted with generous lighting and electrical amenities. A main panel sized smaller than 100 amps may be overloaded, which can cause lights to dim when appliances kick on or may allow frequent home power outages. If this is the case in your home, talk with an electrical contractor about installing a new, larger electrical service panel.

REPLACING AN ELECTRICAL CORD

It's very simple to replace a lamp cord. Disconnect the old cord and snip it off, using wire cutters, a few inches below the bottom of the lamp. Tape the new cord to it with electrical tape and then draw the new cord up through the lamp stem by pulling the old cord out from the top. Remove tape from the cords and discard the old one.

When an appliance cord is defective, it should be replaced rather than repaired. If you can disassemble the appliance to see how the cord is connected, you may be able to handle this job yourself (be sure to unplug the appliance first). Otherwise, call an appliance repairperson.



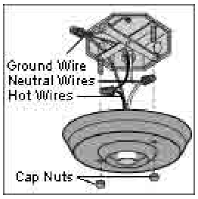
Most cords are secured to the appliance with a strain-relief device, loops, or a clamp that you must loosen or remove. For screw-type, solderless connections, you unscrew the terminal screws that hold the cord and screw a new cord in its place. Cord wires that are twisted together and secured with wire nuts are easy to undo – just remove the wire nuts, untwist the wires, and reverse the process with a new cord (1/2 inch of insulation must be stripped from the wire ends). If the cord's ends are soldered to terminals and you're familiar with soldering techniques, you can remove the old cord and solder a replacement to the terminals. Otherwise, leave this work to an appliance repairperson.

When you replace a cord, be sure to use an identical replacement; take the defective cord with you to the hardware store or electrical supply company to find a perfect match.

REPLACING A LIGHT SOCKET

To replace a socket, remove the old one, then pull the old cord up and clip it off below the Underwriters' knot, or pull a new cord through.

Slip the new socket cap onto the cord. Tie the wires into an Underwriters' knot. Strip about 3/4 inch of insulation from each wire, twist the strands together, and fasten the wires to the socket screws, silver to silver, copper or other to brass. Pull the cap over the Underwriters' knot and socket. Reassemble the bulb, harp, and shade.



If the lamp has more than two sockets, check that the wire connecting the pigtails is in good shape. If it isn't, replace the wire, noting the connecting pattern before disconnecting.

REPLACING A LIGHT FIXTURE

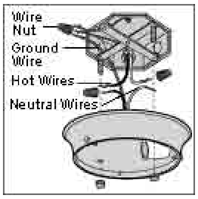
Need a new look for a room? Try replacing the light fixture. Although this is fairly simple, a new fixture may have mounting hardware that does not match your existing hardware. If you have to install new mounting hardware and the fixture is heavy – a large chandelier, perhaps – be sure to mount the hardware to the ceiling joists that can handle the weight. If there are more than two black and white wires for the wiring connection, label the wires with tape before detaching them from the old fixture.

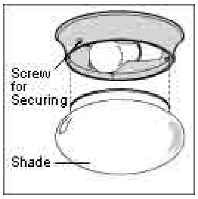
To replace a fixture, first shut off the power to the circuit. Be aware that, although you've turned off the circuit and the switch doesn't operate the light, there may be live (hot) wires in the ceiling box. Don't touch any bare wires until you can test them with a circuit tester to make sure they're off.

Unscrew the bulb, then remove the nuts that hold the ceiling canopy or fixture in place. Carefully lower the canopy or fixture to expose the wires. Unscrew the wire nuts (without touching bare wire ends).

Place the two probes of a circuit tester on the white and black wires simultaneously to be sure they're off. Then lower the fixture away from the wires.

Install the new fixture according to the label directions – in most cases, you just strip about 1/2 inch of the protective insulation from the new wire ends, twist them together with the circuit wires (white to white and black to black), and finish by twisting on wire nuts. Many fixtures also have a grounding screw that should receive a bare grounding wire.





FLUORESCENT LIGHTING TROUBLESHOOTING

Frank Durda

When it comes to solving problems with incandescent lamps, essentially it comes down to just three things: the lamp is burned-out, or the lamp glass is broken, or the lamp is not getting any electricity. Because fluorescent lamps have more components and sometimes lamps work in pairs or other groupings, more things can go wrong and things get a bit more complicated.

The following table describes the most common problem symptoms for each class of fluorescent lighting, what the probable causes are, and what corrective action should be taken. The likely causes for each problem appear in order, starting with the most likely and ending with the least likely cause. The most likely causes tend to be the ones that are easiest to fix.

The table is divided into four categories of fluorescent lighting: Pre-Heat-Start fixtures, Rapid-Start fixtures, Instant-Start fixtures, and Compact Fluorescent lamps. The type most commonly found in office building fixtures are Rapid Start. Pre-Heat and Rapid Start fixtures, or Compact Fluorescent lamps may all be found in homes. Instant Start fixtures are usually found only in commercial facilities and equipment.

PRE-HEAT FIXTURE TROUBLESHOOTING

Problem	Possible Cause	Action
A Lamp or lamps in a fixture won't light at all. No flickering.	No electrical power to the fixture.	If all lamps in the fixture refuse to light or blink, make sure that the electrical power to the fixture is turned on. The power to some fixtures is controlled from a wall switch or power cord, but the fixture may also contain a power switch. Make sure all power control switches are turned on.
	Fixture requires manual starting.	Some desk lamp and under-cabinet fixture models of preheat fluorescent lighting require human intervention each time they are started. The most common models have a pushbutton that must be pressed for two or three seconds and then released in order for the lamp or lamps to start. Such fixtures do not have starters and usually use lamps 18 inches long or shorter. If this fixture has starters, check the other causes.
	Lamp or starter not properly seated in socket or missing.	If the fixture contains a single lamp, make sure the correct starter is locked into its socket, and the lamp is correctly positioned in both lamp holders. Lamps and starters have been known to vibrate or be bumped so that they no longer make electrical contact. Starters turn clockwise to lock into their sockets, while lamps have an alignment mark on each end of the lamp (usually a depression in the metal cap) that indicates where the tube should be positioned when installed. If the fixture has more than one lamp, it is unlikely that all lamps and starters came loose at the same time, so check the other causes.
	Wrong Size Starter.	Although all replaceable starters come in the same size container, they are rated for use with different lamps. FS-2 starters are for use with 18" and 24" lamps. FS-4 starters are for use with 48" lamps. Starters are marked with exactly what size lamps they are to be used with, so be sure to install the right type.
	Lamp or starter worn-out.	If the fixture contains a single lamp, try replacing the lamp and the starter. If the fixture has more than one lamp that isn't working, it is unlikely that all lamps and starters failed at the same time, so check the other causes.
	Ballast failed.	If the fixture contains a single ballast, try replacing the ballast. If the fixture has multiple ballasts and none of the lamps work, the problem is almost certainly a lack of electricity or low supply voltage. Use an AC voltmeter to verify that

		the right electrical voltage is reaching the ballast. Do not measure at the lamp sockets or starter socket. The correct voltage for the ballast should be marked on the ballast.
	Wiring problem in fixture.	This is very unlikely, particularly if the fixture was previously working and then quit. However, if a fixture was recently installed or repaired and hasn't worked since, you may have a wiring error that is causing the problem. A schematic showing the correct wiring is present on almost all ballasts, so compare the wiring of the fixture to that drawing. It is also possible that rodents have damaged wiring or that wiring has been crushed or worn within the fixture, causing a short. Look for any places where the wiring has been caught by the metal parts of the fixture and replace any damaged wiring with wire of the same gauge and insulation temperature. High-temperature electrical tape can be used to cover worn insulation, so long as the wire itself isn't damaged.
The ends of a lamp are lit continuously, but the rest of the lamp is dark.	Starter worn-out.	If the ends of the lamp are constantly lit with no blinking or flickering, it usually means that the starter has gotten stuck in the "start" position. Replace the starter. Note that when this happens, it can greatly reduce the life of the lamp. When the fixture is turned off, if the ends of the lamp appear dark or "smoky" in color, the lamp should be replaced as well.
	Wrong Size Starter.	Although all replaceable starters come in the same size container, they are rated for use with different lamps. FS-2 starters are for use with 18" and 24" lamps. FS-4 starters are for use with 48" lamps. Starters are marked with exactly what size lamps they are to be used with, so be sure to install the right type.
The lamp keeps trying to start (ends blink on and off repeatedly), but lamp doesn't light or remain completely lit, or goes out for periods of time on its own.	Lamp and starter worn-out.	Replace both the lamp and starter for that lamp. Although only the lamp may be beyond use, starters also age and it is prudent to replace both at the same time.
	Wrong type of lamp.	Although many rapid-start lamps are also designed for use in pre-heat fixtures, some are not to be used in pre-heat fixtures. The packaging for the lamp must explicitly state that the lamp may be used in pre-heat fixtures. Note that almost all 34 watt "energy saving" 48" lamps cannot be used in pre-heat fixtures.
	Wrong Size Starter.	Although all replaceable starters come in the same size container, they are rated for use with different lamps. FS-2 starters are for use with 18" and 24" lamps. FS-4 starters are for use with 48" lamps. Starters are marked with exactly what size lamps they are to be used with, so be sure to install the right type.
	Ballast failing.	A somewhat rare situation. However, a ballast can fail in such a way that brand new lamps fail to start after only a few hours or days of use. If you replace the lamps and the starters with the sizes stated on the ballast and if the new lamps also quit working or show significant darkening at the ends in just a few days, replace the ballast. You may have to replace the lamps and starters again, but this may be cheaper than replacing the ballast first when the ballast didn't really need replacing. In addition, when a ballast is malfunctioning and overheats, a safety thermal protector inside the ballast can cause the ballast to abruptly turn off (sometimes with an audible "click" or "ping" sound) and all lamps connected to that ballast will go dark. After several minutes when the ballast has had time to cool-down, the ballast turns back on and the lamps come back on at full brightness and may operate for a period of several minutes before shutting off again. This cycle will repeat endlessly until the problem is corrected, although the cycle may get slightly shorter when the fixture is left on for hours. If you see or hear this condition, replace the ballast and the lamps and the starters that connect to that ballast. Ballasts that are overheating like this are probably also leaking, so watch out for any hot tar that may spill out of an overhead fixture when you are working on it. (If the lamps flicker and blink on and off several times in just a few minutes or seconds, this is probably just a bad lamp(s) or starter(s), not a bad ballast. Replace all lamps and starters connected to the ballast and see if the problem persists before replacing the ballast. If the ballast is faulty, the problem should reappear in an hour or so.)
	Line Voltage low.	With an AC voltmeter, measure the electrical voltage coming to the fixture. Do not measure power at the lamp or starter sockets. The ballast probably won't work properly if the line voltage is more than 10% below the operating voltage specified on the label on the ballast. For example, if a ballast is rated for 120VAC, it probably won't work properly if the line voltage is below 108VAC. Other devices in the typical business or residence

		would not work well if the voltage was so far off. Being 2% off (117VAC instead of 120VAC) probably won't hurt. If you find that the line voltage is too low, contact the power company or an electrician to investigate the problem.
When the fixture is turned on, it takes a long time for a lamp to initially come on.	Slow Starter or Starter worn-out.	As starters wear, they may take more and more time to heat and begin the starting process. Replace the starter. If a new starter still takes a long time (more than two to four seconds) and the lamp doesn't flicker or blink, try a new starter made by a different manufacturer. If the ends of the lamp are constantly lit with no blinking or flickering, it usually indicates that the starter has gotten stuck in the "start" position. Replace the starter. Note that when this happens, it can greatly reduce the life of the lamp. When the fixture is turned off, if the ends of the lamp appear dark or "smoky" in color, the lamp should be replaced as well.
A lamp is bright near the ends, but only half that bright in the middle portion of the lamp.	New Lamp.	Some lamps, particularly those with reduced mercury content (known by abbreviations or model names like "ALTO" or "ECO", have a peculiar behavior. During the first hour or two of use of a brand new lamp, the lamp will glow dimly over most of the length of the lamp, become bright at the ends and gradually (over as much as an hour), the bright areas on each end of the lamp will grow until the entire lamp glows brightly. This behavior may be repeated each time the lamp is turned on for the first 20 to 30 hours of use. After this aging period, this behavior doesn't occur or only takes a minute or so to obtain full brightness across the entire tube. The only action that could be taken would be to leave brand new lamps on for ten to twenty hours to break them in. Otherwise, ignore this artifact.
Lamp starts but glows dimly, may flicker slightly but constantly, and may exhibit "rings" of bright and dim light that appear to move up and down the length of the lamp.	Cold Operating Location.	Fluorescent lamps do not like cold areas, and standard fluorescent lamps exhibit these symptoms when the lamps are cold. Depending on how cold the ambient air temperature is, operating the lamp may eventually warm the gas inside the lamp to the point that the lamp begins operating at or near its full brightness. The artifacts typically begin when air temperatures around the lamp are below 50F. If the air temperature is considerably colder and if the surrounding air is circulating, the lamps will never generate enough heat to keep their internal temperatures above 50F, so the lamps will continue to glow dimly and flicker. The solution here are to use enclosed fixtures that provide insulation from colder air temperatures by trapping a limited amount of air around the lamps. When the lamps are operating, the lamps are insulated from a constant fresh supply of cold air, and gradually the air inside the fixture will heat along with the lamps and the lamps will start to operate normally. In cases where it is not desired to replace the entire fixture, there are plastic lamp sleeves available. The lamp is inserted into these sleeves and a plastic cap on each end seals the lamp inside the plastic tube, allowing only the electrical contacts of the lamp to protrude. This entire assembly is then placed in the socket in the light fixture. Such sleeves are commonly seen on fluorescent lamps in grocery store freezer units, or in outdoor fluorescent lighting used in commercial locations such as the front porch area of stores. Fixtures that use the High-Output lamps (HO) are typically found in outdoor signs and other locations where exposure to cold temperatures is expected. These lamps provide most of their brightness down to 10F. They can also be protected to operate at even lower temperatures by using enclosed fixtures or lamp sleeves.
Lamp works but has a gray "patch" away from the ends of the lamp made up of thousands of black spots. Sometimes the area is shaped like a feather.	Indicates a section of the lamp that is colder than other sections.	Sometimes a place inside a lamp will collect a fine deposit of mercury, which can look like a gray feather inside the lamp. A variety of things can cause marks like this, including a fixture located close to an air vent that blows cold air on that part of the lamp. In most cases, simply rotating the lamp 180 degrees and operating the lamp will cause the mark to gradually dissipate. However, it could eventually reappear again, probably at the same location on the same side of the lamp as before. "Feathers" cause no harm and do not indicate that a lamp is bad or worn out.
Lamp works but has a light or medium gray or brown ring or rings on the inside of the glass near the ends of the lamp.	Normal lamp aging.	As the lamp operates, material stripped from the cathodes at end of the lamp impacts the cathode on the other end of the lamp. Some of this material impacts and is embedded into the phospher coating on the end of the lamps, gradually causing

		the end of the lamps to become partly opaque, developing the smoky or burnt look. This is a normal part of lamp aging, and should be ignored until the lamp eventually fails to start. This aging should be gradual, as the typical fluorescent lamp has at least 10,000 hours of operating life. When the lamp does finally wear out, the discoloration on the end of the lamps can be as dark as coal. The only case where this would be considered a problem would be if new lamps develop these marks within the first 100 hours of use and have trouble starting. That may indicate that the starter was not replaced, the wrong size starter was used, or the ballast is faulty or the wrong type.

RAPID-START FIXTURE TROUBLESHOOTING

Problem	Possible Cause	Action
A Lamp or lamps in a fixture won't light at all. No flickering.	No electrical power to the fixture.	If all lamps in the fixture refuse to light or blink, make sure that the electrical power for the fixture is turned on. The power to some fixtures is controlled from a wall switch or power cord, but the fixture may also contain a power switch. Make sure all power control switches are turned on.
	Lamp(s) not properly seated in socket or missing.	If the fixture contains a single lamp, make sure that the lamp is correctly positioned in both lamp holders. In fixtures with multiple lamps, all lamps may have to be installed and seated in their sockets for the other lamps to operate. Lamps have been known to vibrate or be bumped so that they no longer make electrical contact. Lamps have an alignment mark on each end of the lamp (usually a depression in the metal or plastic end caps) that indicates where the tube should be positioned when installed. If the fixture has more than one lamp, it is unlikely that all lamps came loose at the same time, so check the other causes.
	Lamp(s) worn-out.	If the fixture contains one or two single lamps, replace all of the lamps that aren't lighting. If the fixture has more than two lamps that aren't working, it is unlikely that all lamps failed at the same time, so check the other causes.
	Ballast failed.	If the fixture contains a single ballast, try replacing the ballast. If the fixture has multiple ballasts and none of the lamps work, the problem is almost certainly a lack of electricity or low supply voltage. Use an AC voltmeter to verify that the right electrical voltage is reaching the ballast. Do not measure at the lamp sockets. The correct voltage for the ballast should be marked on the ballast.
	Wiring problem in fixture.	This is very unlikely, particularly if the fixture was previously working and then quit. However, if a fixture was recently installed or repaired and hasn't worked since, you may have a wiring error that is causing the problem. A schematic showing the correct wiring is present on almost all ballasts, so compare the wiring of the fixture to that drawing. It is also possible that rodents have damaged wiring or that wiring has been crushed or worn within the fixture, causing a short. Look for any places where the wiring has been caught by the metal parts of the fixture and replace any damaged wiring with wire of the same gauge and insulation temperature. High-temperature electrical tape can be used to cover worn insulation, so long as the wire itself isn't damaged.
The ends of a lamp are lit continuously, or the lamp intermittently blinks, or the lamp starts and after a while goes out, then tries to start again. The lamps may completely turn off for a while, and them come back on.	Lamp worn out.	Replace all lamps that are not lighting. Rapid-Start fixtures with multiple lamps typically operate the lamps in pairs from the same ballast. In such fixtures, the lamps should be replaced in pairs.
	Wrong type of lamp.	If a fixture contains an energy-saving 34 watt ballast OR an energy saving device that is installed in addition to the ballast, the fixture cannot use 34 watt or other energy-saving lamps. Use only the lamp types listed on the ballast.
	Ballast failing.	A somewhat rare situation. However, a ballast can fail in such a way that brand new lamps fail to start after only a few hours or days of use. If you replace the lamps with the size stated on the ballast and if the new lamps also quit working or show signifi-

		cant darkening at the ends in just a few days, replace the ballast. You may have to replace the lamps again, but this may be cheaper than replacing the ballast when it didn't need replacing. In addition, when a ballast is malfunctioning and overheats, a safety thermal protector inside the ballast can cause the ballast to abruptly turn off (sometimes with an audible "click" or "ping" sound) and all lamps connected to that ballast will go dark. After several minutes when the ballast has had time to cool-down, the ballast turns back on and the lamps come back on at full brightness and may operate for a period of several minutes before shutting off again. This cycle will repeat endlessly until the problem is corrected, although the cycle may get slightly shorter when the fixture is left on for hours. If you see or hear this condition, replace the ballast and the lamps that connect to that ballast. Ballast's that are overheating like this are probably also leaking, so watch out for any hot tar that may spill out of an overhead fixture when you are working on it. (If the lamps flicker and blink on and off several times in just a few minutes or seconds, this is probably just a bad lamp or lamps. not a bad ballast. Replace all lamps connected to the ballast and see if the problem persists before replacing the ballast. If the ballast is faulty, the problem should reappear in an hour or so.)
	Line Voltage low.	With an AC voltmeter, measure the electrical voltage coming to the fixture. Do not measure power at the lamp or starter sockets. The ballast probably won't work properly if the line voltage is more than 10% below the operating voltage specified on the label on the ballast. For example, if a ballast is rated for 120VAC, it probably won't work properly if the line voltage is below 108VAC. Other devices in the typical business or residence would not work well if the voltage was so far off. Being 2% off (117VAC instead of 120VAC) probably won't hurt. If you find that the line voltage is too low, contact the power company or an electrician to investigate the problem.
A lamp is bright near the ends, but only half that bright in the middle portion of the lamp.	New Lamp.	Some lamps, particularly those with reduced mercury content (known by abbreviations or model names like "ALTO" or "ECO", have a peculiar behavior. During the first hour or two of use of a brand new lamp, the lamp will glow dimly over most of the length of the lamp, become bright at the ends and gradually (over as much as an hour), the bright areas on each end of the lamp will grow until the entire lamp glows brightly. This behavior may be repeated each time the lamp is turned on for the first 20 to 30 hours of use. After this aging period, this behavior doesn't occur or only takes a minute or so to obtain full brightness across the entire tube. The only action that could be taken would be to leave brand new lamps on for ten to twenty hours to break them in. Otherwise, ignore this artifact.
Some lamps in a fixture start but only glow dimly, while other lamps in the same fixture may not light at all or may intermittently flicker but generally remain dark. The lamps that are dim remain so indefinitely, but sometimes the lamps will begin to glow brightly immediately if one of the lamps or the fixture is touched, or if other lamps in the area are also turned on. (Replacing the lamps has been tried and it did not correct the problem.)	Lamps are not seated correctly and are not making good contact with socket contacts.	On Bi-pin lamps, it is possible for the lamp to be inserted and held by the sockets, but both pins on each end of the lamp are not making electrical contact. It is also possible to have one end of the lamp misaligned with the socket so that only one pin on that end of the lamp is in a socket while the other pin is outside. Verify that both ends of all lamps are correctly inserted into each socket and that the lamp is rotated to the correct position. This is indicated on the end-cap of the lamp as a ridge or indentation that should align with the slot in the end of the socket. The lamp or lamps that are not installed in the socket correctly can be any of the lamps, including one of the ones glowing dimly. Check all lamps.
	Metal reflectors are not installed or are not electrically connected to the ballast, or the ballast and fixture are not grounded.	Rapid Start and some Instant Start fixtures must be connected to an electrical ground in order to start properly. In addition, the metal reflector of the fixture must be correctly installed so that it is within 1/2 an inch of the lamps AND is in electrical contact with the ballast. A capacitive field is created between lamp and the metal reflector by the ballast during the starting process, and without this field, the lamps may reach normal operating brightness only by an external influence, such as an increase in capacitance caused by you touching the lamps, or by an increase in light (ionization) in the area coming from other sources. A fixture that has a power cord is grounded through the ground prong on the power plug. In North America, the round prong is ground. Some older buildings have outlets

		that do not have grounded outlets (sometimes called two-prong outlets instead of three-prong), and a three-prong cord can be plugged-in only by use of a "cheater" adapter. These "cheaters" do not provide a ground, and this can make a fluorescent fixture malfunction that is connected to them. Have a proper grounded outlet installed for use with the fluorescent fixture. For fixtures that are wired permanently to the building's electrical system, a ground wire should have been provided as part of the building wiring. In some older commercial buildings, the metal conduit served as the ground, but newer electrical codes require a ground wire to be installed, even when metal conduit is used. If the fixture is permanently installed and the building wiring lacks a proper ground, have a ground installed for locations that need them. The most likely cause of a fixture grounding problem that suddenly occurs is in the fixture itself, because fixture designs usually rely on clips, screws or other metal fasteners to force electrical contact between the metal reflector and the ballast. This grounding can be defeated if these parts are missing, or if the fixture or replacement parts have been repainted in such a way that the metal parts now can't make good electrical contact. Always ensure that all fasteners that came with the fixture are reinstalled after servicing. When replacing a ballast, use a piece of sandpaper to scratch the paint off the ballast case at the points where the ballast makes contact with the metal fixture. This will help ensure that the ballast is making good electrical contact with the rest of the fixture. The ground wire from the ballast (normally green in color) must be connected to the electrical supply ground wire and, in some fixtures, a special terminal is provided on the fixture to tie the ballast and supply ground wires together while also making a solid electrical contact with the fixture. Such grounding points may employ a green-colored screw to distinguish them from screws and other hardware meant to mount the fixture.
	Fixture sockets are damaged or broken.	In some cases, a socket may become brittle and the bakelite or plastic material of the socket housing breaks, and this may prevent the electrical contacts from making a solid connection, and may prevent the contacts from being able to grab hold of the lamp and keep it from falling. If parts of the socket appear to be missing or are obviously cracked, replace the damaged socket.
	Line Voltage low.	With an AC voltmeter, measure the electrical voltage coming to the fixture. Do not measure power at the lamp or starter sockets. The ballast probably won't work properly if the line voltage is more than 10% below the operating voltage specified on the label on the ballast. For example, if a ballast is rated for 120VAC, it probably won't work properly if the line voltage is below 108VAC. Other devices in the typical business or residence would not work well if the voltage was so far off. Being 2% off (117VAC instead of 120VAC) probably won't hurt. If you find that the line voltage is too low, contact the power company or an electrician to investigate the problem.
	Ballast failing.	In very rare cases, the portion of the ballast involved in establishing the capacitive field can fail. If a rapid-start fixture persists in having start problems after installing good quality lamps (not those two-for-a-dollar specials), and you have made sure the fixture is grounded properly, replacing the ballast is the remaining option.
Lamp starts but glows dimly, may flicker slightly but constantly, and may exhibit "rings" of bright and dim light that appear to move up and down the length of the lamp.	Cold Operating Location.	Fluorescent lamps do not like cold areas, and standard fluorescent lamps exhibit these symptoms when the lamps are cold. Depending on how cold the ambient air temperature is, operating the lamp may eventually warm the gas inside the lamp to the point that the lamp begins operating at or near its full brightness. The artifacts typically begin when air temperatures around the lamp are below 50F. If the air temperature is considerably colder and if the surrounding air is circulating, the lamps will never generate enough heat to keep their internal temperatures above 50F, so the lamps will continue to glow dimly and flicker. The solution here isto use enclosed fixtures that provide insulation from colder air temperatures by trapping a limited amount of air around the lamps. When the lamps are operating, the lamps are insulated from a constant fresh supply of cold air, and gradually the air inside the fixture will heat along with the lamps and the lamps will start to operate normally. In cases where it is not desired to replace the entire fixture, there are plastic lamp

		sleeves available. The lamp is inserted into these sleeves and a plastic cap on each end seals the lamp inside the plastic tube, allowing only the electrical contacts of the lamp to protrude. This entire assembly is then placed in the socket in the light fixture. Such sleeves are commonly seen on fluorescent lamps in grocery store freezer units, or in outdoor fluorescent lighting used in commercial locations such as the front porch area of stores. Fixtures that use the High-Output lamps (HO) are typically found in outdoor signs and other locations where exposure to cold temperatures is expected. These lamps provide most of their brightness down to 10F. They can also be protected to operate at even lower temperatures by using enclosed fixtures or lamp sleeves.
Lamp works but has a gray "patch" away from the ends of the lamp made up of thousands of black spots. Sometimes the area is shaped like a feather.	Indicates a section of the lamp that is colder than other sections.	Sometimes a place inside a lamp will collect a fine deposit of mercury, which can look like a gray feather inside the lamp. A variety of things can cause marks like this, including a fixture located close to an air vent that blows cold air on that part of the lamp. In most cases, simply rotating the lamp 180 degrees and operating the lamp will cause the mark to gradually dissipate. However, it could eventually reappear again, probably at the same location on the same side of the lamp as before. "Feathers" cause no harm and do not indicate that a lamp is bad or worn out.
Lamp works but has a light- or medium-gray or brown ring or rings on the inside of the glass near the ends of the lamp.	Normal lamp aging.	As the lamp operates, material stripped from the cathodes at end of the lamp impacts the cathode on the other end of the lamp. Some of this material impacts and is embedded into the phospher coating on the end of the lamps, gradually causing the end of the lamps to become partly opaque, developing the smoky or burnt look. This is a normal part of lamp aging, and should be ignored until the lamp eventually fails to start. This aging should be gradual, as the typical fluorescent lamp has at least 10,000 hours of operating life. When the lamp does finally wear out, the discoloration on the end of the lamps can be as dark as coal. The only case where this would be considered a problem would be if new lamps develop these marks within the first 100 hours of use and have trouble starting. That may indicate that the starter was not replaced, the wrong size starter was used, the ballast is faulty or the wrong type, or the fixture and ballast are not properly grounded.

INSTANT-START FIXTURE TROUBLESHOOTING

Problem	Possible Cause	Action
A Lamp or lamps in a fixture won't light at all. No flickering.	No electrical power to the fixture.	If all lamps in the fixture refuse to light or blink, make sure that the electrical power for the fixture is turned on. Make sure all power control switches are turned on. Some instant start fixtures utilize "disconnect" sockets. If any lamps are missing or not fully inserted into both lamp sockets, power to part or all of the entire fixture may be disconnected. Check that all lamps are fully seated.
	Lamp(s) not properly seated in socket or missing.	If the fixture contains a single lamp, make sure that the lamp is correctly positioned in both lamp holders. In fixtures with multiple lamps, all lamps may have to be installed and seated in their sockets for the other lamps to operate. Lamps have been known to vibrate or be bumped so that they no longer make electrical contact. Lamps have an alignment mark on each end of the lamp (usually a depression in the metal or plastic end caps) that indicates where the tube should be positioned when installed. If the fixture has more than one lamp, it is unlikely that all lamps came loose at the same time, so check the other causes.
	Lamp(s) worn-out.	If the fixture contains one or two single lamps, replace all of the lamps that aren't lighting. If the fixture has more than two lamps that aren't working, it is unlikely that all lamps failed at the same time, so check the other causes.
	Ballast failed.	If the fixture contains a single ballast, try replacing the ballast.

		If the fixture has multiple ballasts and none of the lamps work, the problem is almost certainly a lack of electricity or low supply voltage. Use an AC voltmeter to verify that the right electrical voltage is reaching the ballast. Do not measure at the lamp sockets. The correct voltage for the ballast should be marked on the ballast.
	Wiring problem in fixture.	This is very unlikely, particularly if the fixture was previously working and then quit. However, if a fixture was recently installed or repaired and hasn't worked since, you may have a wiring error that is causing the problem. A schematic showing the correct wiring is present on almost all ballasts, so compare the wiring of the fixture to that drawing. It is also possible that rodents have damaged wiring or that wiring has been crushed or worn within the fixture, causing a short. Look for any places where the wiring has been caught by the metal parts of the fixture and replace any damaged wiring with wire of the same gauge and insulation temperature. High-temperature electrical tape can be used to cover worn insulation, so long as the wire itself isn't damaged.
The ends of a lamp are lit continuously, or the lamp intermittently blinks, or the lamp starts and after a while goes out, then tries to start again. The lamps may completely turn off for a while, and then come back on.	Lamp worn out.	Replace all lamps that are not lighting. Rapid-Start fixtures with multiple lamps typically operate the lamps in pairs from the same ballast. In such fixtures, the lamps should be replaced in pairs.
	Wrong type of lamp.	If a fixture contains an energy-saving 34 watt ballast OR an energy saving device that is installed in addition to the ballast, the fixture cannot use 34 watt or other energy-saving lamps. Use only the lamp types listed on the ballast.
	Ballast failing.	A somewhat rare situation. However, a ballast can fail in such a way that brand new lamps fail to start after only a few hours or days of use. If you replace the lamps with the size stated on the ballast and if the new lamps also quit working or show significant darkening at the ends in just a few days, replace the ballast. You may have to replace the lamps again, but this may be cheaper than replacing the ballast when it didn't need replacing. In addition, when a ballast is malfunctioning and overheats, a safety thermal protector inside the ballast can cause the ballast to abruptly turn off (sometimes with an audible "click" or "ping" sound) and all lamps connected to that ballast will go dark. After several minutes when the ballast has had time to cool down, the ballast turns back on and the lamps come back on at full brightness and may operate for a period of several minutes before shutting off again. This cycle will repeat endlessly until the problem is corrected, although the cycle may get slightly shorter when the fixture is left on for hours. If you see or hear this condition, replace the ballast and the lamps that connect to that ballast. Ballasts that are overheating like this are probably also leaking, so watch out for any hot tar that may spill out of an overhead fixture when you are working on it. (If the lamps flicker and blink on and off several times in just a few minutes or seconds, this is probably just a bad lamp or lamps. not a bad ballast. Replace all lamps connected to the ballast and see if the problem persists before replacing the ballast. If the ballast is faulty, the problem should reappear in an hour or so.)
	Line Voltage low.	With an AC voltmeter, measure the electrical voltage coming to the fixture. Do not measure power at the lamp or starter sockets. The ballast probably won't work properly if the line voltage is more than 10% below the operating voltage specified on the label on the ballast. For example, if a ballast is rated for 120VAC, it probably won't work properly if the line voltage is below 108VAC. Other devices in the typical business or residence would not work well if the voltage was so far off. Being 2% off (117VAC instead of 120VAC) probably won't hurt. If you find that the line voltage is too low, contact the power company or an electrician to investigate the problem.
A lamp is bright near the ends, but only half that bright in the middle portion of the lamp.	New Lamp.	Some lamps, particularly those with reduced mercury content (known by abbreviations or model names like "ALTO" or "ECO", have a peculiar behavior. During the first hour or two of use of a brand new lamp, the lamp will glow dimly over most of the length of the lamp, become bright at the ends and gradually (over as much as an hour), the bright areas on each end of the lamp will grow until the entire lamp glows brightly. This behavior may be repeated each time the lamp is turned on for the first 20 to 30

		hours of use. After this aging period, this behavior doesn't occur or only takes a minute or so to obtain full brightness across the entire tube. The only action that could be taken would be to leave brand new lamps on for ten to twenty hours to break them in. Otherwise, ignore this artifact.
Lamp starts but glows dimly, may flicker slightly but constantly, and may exhibit "rings" of bright and dim light that appear to move up and down the length of the lamp.	Cold Operating Location.	Fluorescent lamps do not like cold areas, and standard fluorescent lamps exhibit these symptoms when the lamps are cold. Depending on how cold the ambient air temperature is, operating the lamp may eventually warm the gas inside the lamp to the point that the lamp begins operating at or near its full brightness. The artifacts typically begin when air temperatures around the lamp are below 50F. If the air temperature is considerably colder and if the surrounding air is circulating, the lamps will never generate enough heat to keep their internal temperatures above 50F, so the lamps will continue to glow dimly and flicker. The solution here is to use enclosed fixtures that provide insulation from colder air temperatures by trapping a limited amount of air around the lamps. When the lamps are operating, the lamps are insulated from a constant fresh supply of cold air, and gradually the air inside the fixture will heat along with the lamps and the lamps will start to operate normally. In cases where it is not desired to replace the entire fixture, there are plastic lamp sleeves available. The lamp is inserted into these sleeves and a plastic cap on each end seals the lamp inside the plastic tube, allowing only the electrical contacts of the lamp to protrude. This entire assembly is then placed in the socket in the light fixture. Such sleeves are commonly seen on fluorescent lamps in grocery store freezer units, or in outdoor fluorescent lighting used in commercial locations such as the front porch area of stores. Fixtures that use the High-Output lamps (HO) are typically found in outdoor signs and other locations where exposure to cold temperatures is expected. These lamps provide most of their brightness down to 10F. They can also be protected to operate at even lower temperatures by using enclosed fixtures or lamp sleeves.
Lamp works but has a gray "patch" away from the ends of the lamp made up of thousands of black spots. Sometimes the area is shaped like a feather.	Indicates a section of the lamp that is colder than other sections.	Sometimes a place inside a lamp will collect a fine deposit of mercury, which can look like a gray feather inside the lamp. A variety of things can cause marks like this, including a fixture located close to an air vent that blows cold air on that part of the lamp. In most cases, simply rotating the lamp 180 degrees and operating the lamp will cause the mark to gradually dissipate. However, it could eventually reappear again, probably at the same location on the same side of the lamp as before. "Feathers" cause no harm and do not indicate that a lamp is bad or worn out.
Lamp works but has a light or medium gray or brown ring or rings on the inside of the glass near the ends of the lamp.	Normal lamp aging.	As the lamp operates, material stripped from the cathodes at end of the lamp impacts the cathode on the other end of the lamp. Some of this material impacts and is embedded into the phospher coating on the end of the lamps, gradually causing the end of the lamps to become partly opaque, developing the smoky or burnt look. This is a normal part of lamp aging, and should be ignored until the lamp eventually fails to start. This aging should be gradual, as the typical fluorescent lamp has at least 10,000 hours of operating life. When the lamp does finally wear out, the discoloration on the end of the lamps can be as dark as coal. The only case where this would be considered a problem would be if new lamps develop these marks within the first 100 hours of use and have trouble starting. That may indicate that the starter was not replaced, the wrong size starter was used, the ballast is faulty or the wrong type, or the fixture and ballast are not properly grounded.

COMPACT FLUORESCENT TROUBLESHOOTING

Problem	Possible Cause	Action
The lamp won't light.	No electrical power to the socket.	Make sure all power control switches are turned on. This can be tested by removing the compact fluorescent lamp and temporarily installing a good incandescent lamp to verify that it lights.
	Lamp assembly is burned-out.	Replace the lamp assembly.
	Lamp cannot make electrical contact in the socket.	In some fixture designs such as the recessed models, a compact fluorescent lamp assembly may be too large to screw entirely into the socket through the hole provided in the fixture reflector, so the lamp can't receive electrical power. If the lamp doesn't feel like it is completely in the socket but can't be inserted further into the fixture,

		some other type of lamp may have to be used in this fixture. Alternatively, hardware stores sell a lamp socket "extender", a device roughly two inches in length and it consists of a lamp socket and a lamp screw base. This is inserted into the existing socket, then the lamp is inserted into the extender. This gets the lamp assembly further away from the base of the fixture, but it may also make the lamp extend out of the fixture.
	Circuit is connected to a dimmer or solid state control.	Most compact fluorescent lamps cannot be used with dimmers, and will not function properly or at all when connected to these circuits. Dimmable compact fluorescent lamps are available and this capability is clearly marked. Also, some photocell and timer controls don't use a relay or electrical contact to turn the power on and off. Instead, they use a solid state electronic component – usually a triac – to control the power flow. Unfortunately, triacs don't allow 100% of the electricity to flow through when they are conducting, and this can interfere with the electronics in the compact fluorescent lamp base. If the compact fluorescent lamp works correctly in another socket that is controlled from a wall switch, this could be the problem.
	Socket on an Emergency Lighting System.	Some emergency and exit lighting systems in commercial buildings use Direct Current, and some types of compact fluorescent lamps cannot be used here unless the lamp packaging specifically says the lamps can be used in this situation.
The ends of a lamp tubing are lit continuously (usually right at the base), or the lamp intermittently blinks, or the lamp starts and after a while goes out, then tries to start again.	Lamp worn out.	Replace the lamp. If the lamp can be replaced, try replacing just the lamp. Otherwise, replace the entire assembly.
	Circuit is connected to a dimmer or solid state control.	Most compact fluorescent lamps cannot be used with dimmers, and will not function properly or at all when connected to these circuits. Dimmable compact fluorescent lamps are available and this capability is clearly marked. Also, some photocell and timer controls don't use a relay or electrical contact to turn the power on and off. Instead, they use a solid state electronic component – usually a triac – to control the power flow. Unfortunately, triacs don't allow 100% of the electricity to flow through when they are conducting, and this can interfere with the electronics in the compact fluorescent lamp base. If the compact fluorescent lamp works correctly in another socket that is controlled from a wall switch, this could be the problem.
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Lamp works but has a gray "patch" away from the ends of the lamp tubing that are made up of thousands of black spots. Sometimes the area is shaped like a feather.	Indicates a section of the lamp that is colder than other sections.	Sometimes a place inside a lamp will collect a fine deposit of mercury, which can look like a gray feather inside the lamp. A variety of things can cause marks like this, including a fixture located close to an air vent that blows cold air on that part of the lamp. In most cases, simply rotating the lamp 180 degrees and operating the lamp will cause the mark to gradually dissipate. However, it could eventually reappear again, probably at the same location on the same side of the lamp as before. "Feathers" cause no harm and do not indicate that a lamp is bad or worn out.
Lamp works but has a gray or brown ring or rings on the inside of the glass near the ends of the lamp tubing.	Normal lamp aging.	As the lamp operates, material stripped from the cathodes at end of the lamp impacts the cathode on the other end of the lamp. Some of this material impacts and is embedded into the phospher coating on the end of the lamps, gradually causing the end of the lamps to become partly opaque, developing the smoky or burnt look.

		This is a normal part of lamp aging, and should be ignored until the lamp eventually fails to start. This aging should be gradual, as the typical fluorescent lamp has at least 10,000 hours of operating life. When the lamp does finally wear out, the discoloration on the end of the lamps can be as dark as coal. The only case where this would be considered a problem would be if new lamps develop these marks within the first 100 hours of use and have trouble starting. This may indicate a low- or high-voltage power problem in the socket or a faulty lamp assembly.

GENERATION OF LIGHT REFERENCE GUIDE

Conservation Bureau of Ontario; Gerry Cornwell, LC, Architectural Lighting Design;
Scott Rouse, P.Eng., MBA, CEM, Energy@Work; Ontario Hydro, Ontario Power Generation

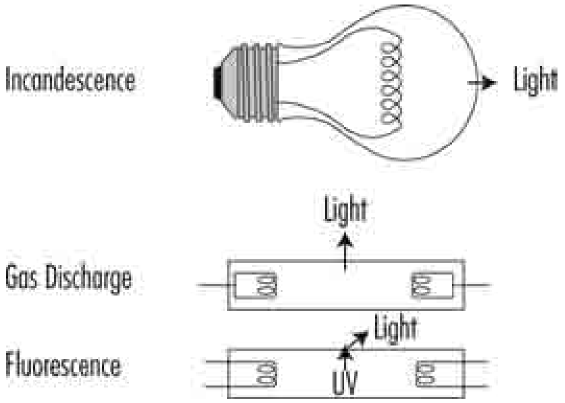
GENERATION OF LIGHT

A. LIGHT SOURCES

Definition

Many different processes convert energy into visible radiation (light).

Some basic processes are described below.



Incandescence

- Solids and liquids emit visible radiation when they are heated to temperatures above 1,000 K.
- The intensity increases and the appearance becomes whiter as the temperature increases.
- This phenomenon is known as incandescence or temperature radiation.
- Application: incandescent lamps.

Luminescence

- Luminescence is the emission of light not ascribed directly to incandescence.
- Two important types of luminescence are electric or gas discharge, and fluorescence.

Electroluminescence

- Electroluminescence is the emission of light when low voltage direct current is applied to a semi-conductor device containing a crystal and a p-n junction.
- The most common electroluminescent device is the LED.

Electric or Gas Discharge

- When an electric current passes through a gas, the atoms and molecules emit radiation, whose spectrum is characteristic of the elements present.
- In low pressure discharge, the gas pressure is approximately 1/100 atm or 0.147 PSI.
- In high pressure discharge, the gas pressure is approximately 1 to 2 atm or 14.7 to 29.4 PSI.
- Application: gas discharge lamps.

Fluorescence

- Radiation at one wavelength is absorbed, usually by a solid, and is re-emitted at a different wavelength.
- When the re-emitted radiation is visible and the emission happens only during the absorption time, the phenomenon is called fluorescence.
- If the emission continues after the excitation, the phenomenon is called phosphorescence.
- In the fluorescent lamp, the ultraviolet radiation resulting from the gas discharge is converted into visible radiation by a phosphor coating on the inside of the tube.
- Application: fluorescent, phosphor-coated HID lamps.

B. LAMP TYPES

Definition

An electric lamp is a device converting electric energy into light.

Lamp Types by Light Generation Method

- Incandescent lamps
- Gas discharge lamps
- Low pressure discharge
  - fluorescent lamps
  - low pressure sodium (LPS) lamps
- High pressure or HID
  - mercury vapour (MV) lamps
  - MH lamps
  - high pressure sodium (HPS) lamps
- Electroluminescent lamps
  - LEDs

Lamp Types by Standard Classification

- Incandescent lamps
- Fluorescent lamps
- HID lamps
- mercury vapour (MV) lamps
- metal halide (MH) lamps
- high pressure sodium (HPS) lamps
- Low pressure sodium (LPS) lamps
- LED sources

Lamp Type	Efficacy (Lumens per Watt)	Rated Average Life (hours)
Incandescent	10 to 35	1,000 to 4,000
Mercury Vapour	20 to 60	24,000+
Light Emitting Diode	20 to 40	see below
Fluorescent	40 to 100	6,000 to 24,000
Metal Halide	50 to 110	6,000 to 20,000
High Pressure Sodium	50 to 140	24,000 to 40,000
Low Pressure Sodium	100 to 180	16,000

Rated Average Life

- Rated average life is the total operated hours when 50% of a large group of lamps still survive; it allows for individual lamps to vary considerably from the average.
- Incandescent lamp life can be extended by use of dimming to reduce maximum power.
- Compact fluorescent lamps have relatively long lives of about 10,000 hours.
- Gas discharge lamps have long lives of about 20,000 hours or more.
- LED sources have life based on different criteria. When the LED has lost 50% of its original output, it is considered failed. This is a range from 50,000 to 100,000 hours. This methodology is used by most manufacturers.

C. LIGHTING SYSTEMS

Lighting Unit or Luminaire

A lighting unit consists of:

- a lamp or lamps,
- a ballast (for gas discharge lamps),
- a fixture or housing,
- an internal wiring and sockets,
- a diffuser (louver or lens).

Lighting System

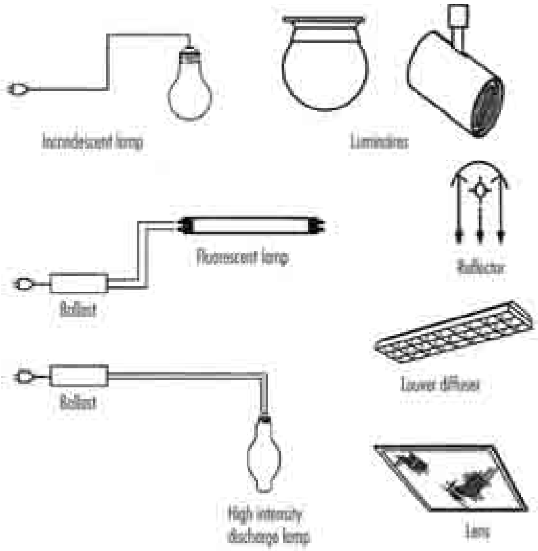
A typical lighting system consists of:

- luminaires,
- lighting control system(s).

Lighting System Environment

A lighting system environment consists of:

- room (ceiling, wall, floor),
- room objects.



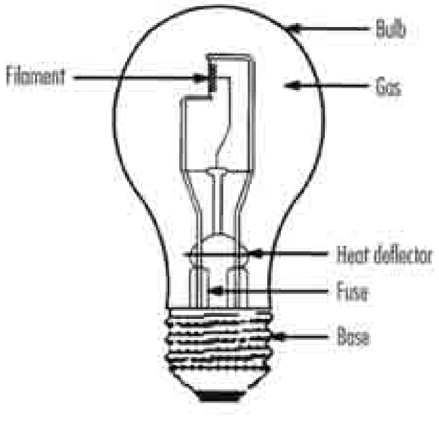
INCANDESCENT LAMPS

A. STANDARD INCANDESCENT LAMPS

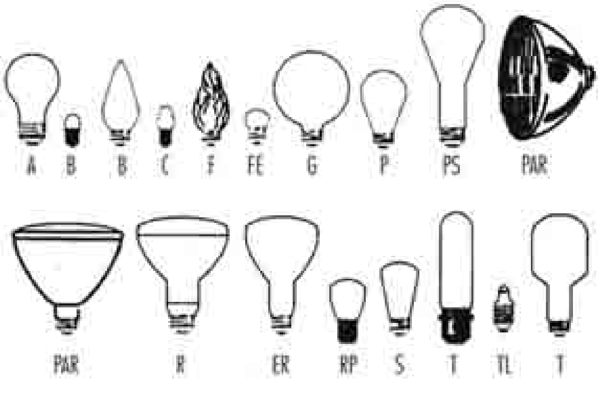
Construction

- A typical construction of an incandescent lamp is shown in the figure below.
- An incandescent lamp produces light by using electric current to heat a metallic filament to a high temperature (above 5000° C/9000° F).
- A tungsten filament is used because of its high melting point and low rate of evaporation at high temperatures.
- The filament is coiled to shorten the overall length and to reduce thermal loss.
- The filament is enclosed in a glass bulb filled with inert gas at low pressure.
- The inert gas permits operation at higher temperatures, compared to vacuum, resulting in a smaller evaporation rate of the filament.
- The bulbs are often frosted on the inside to provide a diffused light instead of the glaring brightness of the unconcealed filament.

Typical Construction of an Incandescent Lamp



Shapes and Designation



Shape	Code	
A	Arbitrary (standard)	– universal use for home lighting
B	Bullet	– decorative
BR	Bulging reflector	– for substitution of incandescent R lamps
C	Cone shape	– used mostly for small appliances and indicator lamps
ER	Elliptical reflector	– for substitution of incandescent R lamps
F	Flame	– decorative interior lighting
G	Globe	– ornamental lighting and some floodlights
P	Pear	– standard for streetcar and locomotive headlights
PAR	Parabolic aluminized	– used in spotlights and floodlights reflector
S	Straight	– lower wattage lamps – sign and decorative
T	Tubular	– showcase and appliance lighting

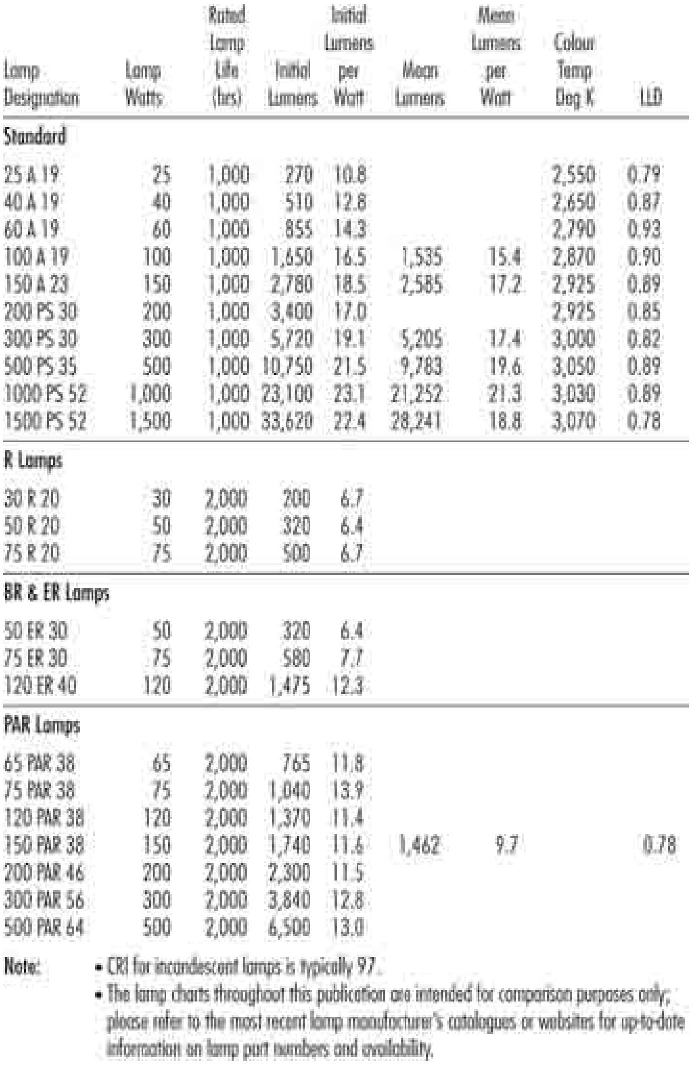
Lamp Designation

A lamp designation consists of a number to indicate the wattage, a shape code and a number to indicate the approximate major diameter.

Example: 60A19
60: Wattage (60 W)
A: Bulb shape
19: Maximum bulb diameter, in eighths of an inch.

Characteristics	
Colour rendering index	– 97 (CRI) – excellent CRI
Colour temperature	– 2,500 to 3,000 K – warm colour
Luminous efficacy	– 10 to 35 lumens per watt – lowest efficacy of all light sources – efficacy increases with lamp size
Lamp life (hours)	– 1,000 to 4,000 (typical 1,000) – shortest life of all light sources – longer life lamps have lower efficacy
General	– first developed and most common lamps
Lamp configuration	– point source
Lamp watts	– 1 to 1,500 W
Lamp lumen	– 80% to 90% depreciation factor (LLD)
Warm-up time	– instant
Restrike time	– instant
Lamp cost	– low – lowest initial cost – highest operating cost
Main applications	– residential – merchandising display lighting

More Information:
- Refer to lamp manufacturers' catalogues.



Lamp Designation	Lamp Watts	Rated Lamp Life (hrs)	Initial Lumens	Initial Lumens per Watt	Mean Lumens	Mean Lumens per Watt	Colour Temp Deg K	LLD
Standard								
25 A 19	25	1,000	270	10.8			2,550	0.79
40 A 19	40	1,000	510	12.8			2,650	0.87
60 A 19	60	1,000	855	14.3			2,790	0.93
100 A 19	100	1,000	1,650	16.5	1,535	15.4	2,870	0.90
150 A 23	150	1,000	2,780	18.5	2,585	17.2	2,925	0.89
200 PS 30	200	1,000	3,400	17.0			2,925	0.85
300 PS 30	300	1,000	5,720	19.1	5,205	17.4	3,000	0.82
500 PS 35	500	1,000	10,750	21.5	9,783	19.6	3,050	0.89
1000 PS 52	1,000	1,000	23,100	23.1	21,252	21.3	3,030	0.89
1500 PS 52	1,500	1,000	33,620	22.4	28,241	18.8	3,070	0.78
R Lamps								
30 R 20	30	2,000	200	6.7				
50 R 20	50	2,000	320	6.4				
75 R 20	75	2,000	500	6.7				
BR & ER Lamps								
50 ER 30	50	2,000	320	6.4				
75 ER 30	75	2,000	580	7.7				
120 ER 40	120	2,000	1,475	12.3				
PAR Lamps								
65 PAR 38	65	2,000	765	11.8				
75 PAR 38	75	2,000	1,040	13.9				
120 PAR 38	120	2,000	1,370	11.4				
150 PAR 38	150	2,000	1,740	11.6	1,462	9.7		0.78
200 PAR 46	200	2,000	2,300	11.5				
300 PAR 56	300	2,000	3,840	12.8				
500 PAR 64	500	2,000	6,500	13.0				

Note:
- CRI for incandescent lamps is typically 97.
- The lamp charts throughout this publication are intended for comparison purposes only; please refer to the most recent lamp manufacturer's catalogues or websites for up-to-date information on lamp part numbers and availability.

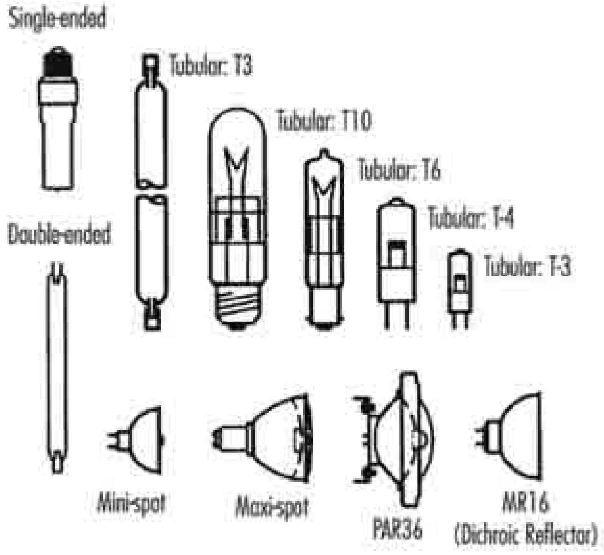
B. TUNGSTEN HALOGEN LAMPS

Construction

- The quartz tungsten halogen lamp is another type of incandescent lamp.
- The conventional incandescent lamp loses filament material by evaporation which is deposited on the bulb wall, leading to bulb blackening and reduced lamp efficacy during the life of the lamp.
- When a halogen element is added to the filling gas under certain design conditions, a chemical reaction occurs, as a result of which evaporated tungsten is redeposited on the filament, preventing any deposits on the bulb wall.
- The bulb of the tungsten halogen lamp is normally made of quartz glass to withstand the lamp's high-temperature operating conditions.
- The fixture often incorporates a reflector for better heat dissipation and beam control.

Shapes and Designation

Shape	Code
Tubular: T3	Line voltage tungsten halogen lamp – double-ended
Tubular: T10	Line voltage tungsten halogen lamp – single-ended
Tubular: T6	Line voltage tungsten halogen lamp – single-ended
Tubular: T-4	Line voltage tungsten halogen lamp – without reflector
Tubular: T-3	Low voltage tungsten halogen lamp – without reflector
Maxi-spot	Low voltage tungsten halogen lamp – with reflector
Mini-spot	Low voltage tungsten halogen lamp – with reflector
PAR 36	Low voltage tungsten halogen lamp – PAR36 reflector
MR16	Low voltage tungsten halogen lamp – MR16 reflector



Low Voltage Tungsten Halogen

- Operates at low voltage – mainly 12 V,
- Each fixture includes a transformer – supplying the low voltage to the lamp and are compact in size,
- These are more efficient than standard incandescent,
- These have longer life than standard incandescent,
- These are used mainly for display lighting.

Lamp Designation	Lamp Watts	Rated Lamp Life (hrs)	Initial Lumens	Initial Lumens per Watt	Mean Lumens	Mean Lumens per Watt	Colour Temp Deg K	LLD
Single-Ended Quartz								
Q 75CL	75	2,000	1,400	18.7				
Q 100 CL	100	750	1,800	18.0			3,000	
Q 150 CL/DC	150	1,000	2,800	18.7	2,688	17.9	2,850	0.96
Q 250 CL/DC	250	2,000	5,000	20.0	4,850	19.4	2,950	0.97
Q 400 CL/MC	400	2,000	8,250	20.6			2,950	
Q 500 CL/DC	500	2,000	10,450	20.9			2,950	
Double-Ended Quartz								
Q 200 T3/CL	200	1,500	3,460	17.3			2,850	0.96
Q 300 T3/CL	300	2,000	5,950	19.8			2,950	0.96
Q 400 T4/CL	400	2,000	7,750	19.4			2,950	0.96
Q 500 T3/CL	550	2,000	11,100	22.2	10,767	21.5	3,000	0.96
Q1000 T6/CL	1,000	2,000	23,400	23.4			3,050	0.96
Q1500 T3/CL	1,500	2,000	35,800	23.9	34,726	23.2	3,050	0.96
Low Voltage MR Types								
20MR16FL	20W	4,000	700 CBCP					
50MR16FL	50W	4,000	2,000 CBCP					
65MR16FL	65W	4,000	2,100 CBCP					

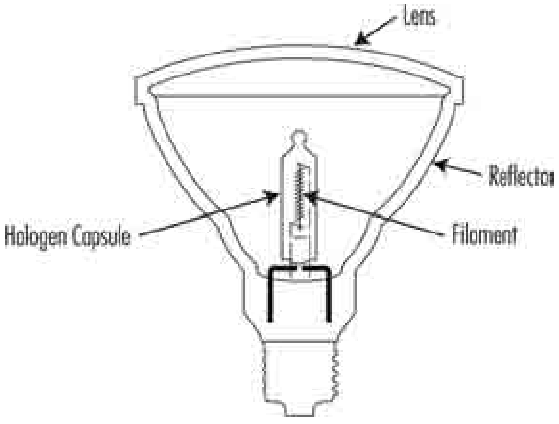
Notes:
- CRI for incandescent lamps is typically 97.
- CRI for tungsten halogen (quartz) lamps is slightly better than other incandescent lamps
- CBCP = Centre Beam Candle Power, used instead of lumens with the low voltage reflector lamps

See Also:
- Lamp manufacturers' catalogues.

C. HALOGEN PAR LAMPS

General Description

- Halogen PAR lamps are lamps with a Parabolic Aluminum Reflector (PAR) which use a halogen capsule instead of a simple filament.
- The halogen capsule includes a tungsten filament and halogen gas.



PAR Lamp Families

- PAR lamps have evolved into four families, listed below, from lowest to highest efficiency:
- standard PAR lamps
- energy saving PAR lamps
- halogen PAR lamps
- Infra Red (IR) halogen PAR lamps.
- All PAR lamps have an aluminum or silver coating reflector on part of the bulb's surface.
- PAR lamps are used for directional lighting, i.e., highlighting or spot lighting.
- Most common size is the PAR38.
- Other sizes include PAR30, PAR20 and PAR16.
- Beam spreads are described as narrow spot (NS), spot (SP) and flood (FL).

Standard PAR Lamps (see also Section 7a, Incandescent Lamps)

- Use a tungsten filament but no halogen gas, i.e., no halogen capsule.
- Lamp watts: 75 W, 100 W, 150 W
- Life: 2,000 hours.

Halogen PAR Lamps

- Halogen PAR lamps use a halogen capsule instead of a tungsten filament.
- Lamp watts: 45 W, 65 W, 90 W.
- Life: 2,000 hours.

PAR 38 Lamp Replacements

	Standard PAR	Energy Saving PAR	Halogen PAR	IR Halogen PAR
	75	55,65	45	
	100	80,85	-	-
	150	120	90	60
	-	-	-	100
Life Hours	2,000	2,000	2,000	2,000
Energy	-	20% less	40% less	60% less
Light	-	same	same	same
Colour	-	same	whiter	whiter
GE Brand	PAR	Watt-Miser PAR	Halogen Performance Plus PAR	Halogen IR-PAR
Philips Brand	PAR	Econ-O-PAR	Masterline	-
Sylvania Brand	PAR	Super Saver	Capsylite	-

Notes:
- Replacements provide about the same light beam candlepower around the centre of the beam.
- The standard PAR is used as a basis for the comparisons shown in the table.

Applications

Highlighting merchandise in stores and window displays:

- Downlights,
- Accent lighting,
- Outdoor lighting.

Advantages

Halogen PAR lamps have many advantages over standard and energy saving PAR lamps:

- energy savings in the order of 40% – 60%;
- whiter light;
- constant light output throughout lamp life without lamp darkening.

Limitations

Halogen PAR lamps are more expensive than standard and energy saving PAR.

Assessment

- Halogen PAR lamps provide energy savings which outweigh the lamp price difference in less than a year.
- Halogen PAR lamps provide better quality light.

Lamp Designation	Lamp Watts	Rated Lamp Life (hrs)	Initial Lumens	Initial Lumens per Watt	Mean Lumens	Mean Lumens per Watt	Colour Temp Deg K	LLD
PAR Quartz								
Q90 PAR38	90	2,000	1,740	19.3				0.96
Q150 PAR38	140	4,000	2,000	13.3	1,900	12.7	2,900	
Q250 PAR38	250	6,000	3,220	12.9			2,900	
Q500 PAR56	500	4,000	7,000	14.0			2,950	
Q1000 PAR64	1,000	4,000	19,400	19.4			3,000	

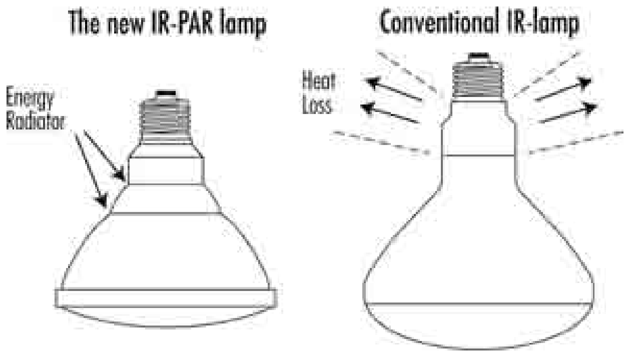
D. HALOGEN PAR AND MR IR (INFRARED) LAMPS

- Halogen PAR IR lamps use a halogen capsule with an infrared (IR) coating film on the capsule surface.
- The IR film is visually transparent and reflects heat back to the filament, making the lamp more efficient.
- These lamps are the most efficient incandescent PAR lamps.
- Lamp watts: 40 W, 50 W, 55 W, 60 W, 80 W, 100 W, and others.
- Life: 3,000 to 6,000 hours.
- These are an excellent replacement for conventional incandescent PAR lamps.

Standard incandescent PAR Lamp:

150PAR38fl, 2,000 hrs, 1,700 initial lumens, 11.3 lm/W
Halogen PAR Lamp:
120PAR38FL, 2,000 hrs, 1,900 initial lumens, 15.8 lm/W
Halogen HIR PAR Lamp:
90PAR38HIR/FL, 4,000 hrs, 2,030 initial lumens, 22.5 lm/W

E. INFRARED HEAT LAMPS



- The Energy Radiator reflects the heat forward
- The heat loss in the conventional (Soft Glass) IR lamp
- Skirted PAR lamp base for increased support

General Description

Infrared heat lamps, also known as IR lamps, or simply heat lamps, are specially-designed incandescent lamps which produce mostly heat and little light.

Types
There are two basic types:
- PAR type – i.e., parabolic aluminum reflector lamps
- R type – i.e., reflector type lamps.

PAR type lamps are newer and more efficient. They include the following sizes:

- 175 W PAR 38,
- 100 W PAR 38.

R type lamps are older and have been used more extensively. They include the following sizes:

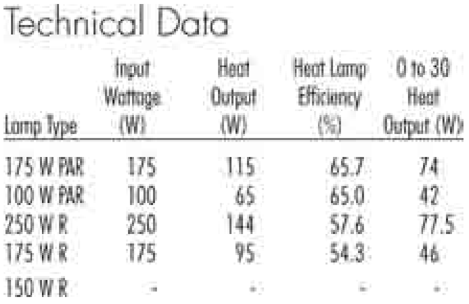
- 250 W R40,
- 175 W R40,
- 150 W R40.
- The 250 W R40 lamp is presently the most widely-used heat lamp in the market.
- Most infrared heat lamps have a red front glass, but lamps with clear white glass are also available.

PAR Lamps Can Replace R Lamps

- PAR lamps are newer and more efficient than R lamps.
- PAR lamps can replace higher wattage R lamps with an equivalent heat output.

Typical replacements:

- 175 W PAR can replace 250 W R lamp
- 100 W PAR can replace 175 W and 150 W R lamps
- The parameters used to compare the two types of lamps are listed below.



Technical Data

Lamp Type	Input Wattage (W)	Heat Output (W)	Heat Lamp Efficiency (%)	0 to 30 Heat Output (W)
175 W PAR	175	115	65.7	74
100 W PAR	100	65	65.0	42
250 W R	250	144	57.6	77.5
175 W R	175	95	54.3	46
150 W R	-	-	-	-

- Input wattage is the nominal lamp wattage.
- Heat output is the useful heat available from the front of the lamp i.e., the heat produced in a solid angle of 90 degrees around the lamp axis in the front hemisphere.
- The heat output numbers included in the table above have been measured in a laboratory test.
- Heat lamp efficiency is defined as the ratio of the heat output over the nominal input wattage.
- Heat output in the 0° to 30° zone is the heat output near the centre axis of the lamp.

Lifetimes

- Nominal lifetimes are listed below (manufacturers' data):

Lamp Type	Expected Lifetime(hrs)
175 W PAR	5,000
100 W PAR	5,000
250 W R	5,000
175 W R	5,000
150 W R	5,000

- Lamp life is defined statistically as the time in hours at which 50% of the lamps are still functioning (while 50% have failed).
- The expected lifetime of a single lamp is 5,000 hours, but by definition, the actual lifetime can be higher or lower.
- PAR lamps have a more rugged construction and use a tempered glass not easily broken by thermal shock or mechanical impact.
- In farm applications, typical conditions include high humidity, i.e., RH at least 75% and ammonia levels from 25 to 35 ppm, with an expected negative effect on lamp life.
- Fluctuations in voltage are common in farms and have a negative effect since higher voltages reduce the expected lifetime.
- Monitoring line voltage of a large number of lamps in a real farm setting and recording failure rates would provide a comparison of reliability and lamp life between PAR and R type lamps.

175 W PAR Lamps Can Replace 250 W R Lamps

- The technical data listed on the previous page indicates that the 175 W PAR lamp can be a more efficient replacement for the 250 W R lamp.
- Replacement results in savings of 75 W per lamp, i.e., 30% energy savings.
- Heat output is reduced by 29 W.
- Heat output in the 0° to 30° zone, i.e., heat output near the lamp axis zone, is almost the same for the old and the new lamp (only 3.5 W less).
- The heat lamp efficiency is improved.

100 W PAR Lamps Can Replace 175 W R Lamps

- The 100 W PAR lamp can be a more efficient replacement for the 175 W R lamp.
- Replacement results in savings of 75 W per lamp, i.e., 43% energy savings.
- Heat output is reduced by 30 W.
- Heat output in the 0° to 30° zone, i.e., heat output near the lamp axis zone, is almost the same for the old and the new lamp (only 4 W less).
- The heat lamp efficiency is improved.

Applications

- Farm animal heating;
- In farm animal heating where lamps are on continuously;
- Restaurants also use them for keeping food warm.

Assessment

- PAR heat lamps offer a more efficient and overall better alternative to R type of heat lamps.

FLUORESCENT LAMP BALLASTS

A. GENERAL

Definition

A ballast is a device used with a gas discharge lamp to provide the necessary starting and operating electrical conditions.

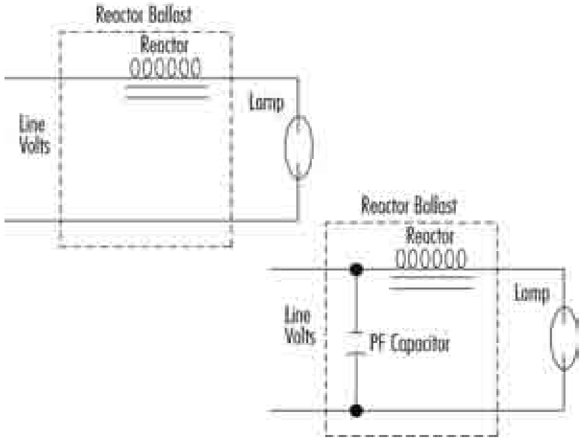
Function

- The ballast supplies the right voltage to start and operate the lamp.
- The ballast limits current to a gas discharge lamp during operation – the resistance of a gas discharge lamp becomes negligible once the arc has been struck.
- The ballast prevents any voltage or current fluctuations caused by the arc discharge from reflecting into the line circuit.
- The ballast compensates for the low power factor characteristic of the arc discharge.

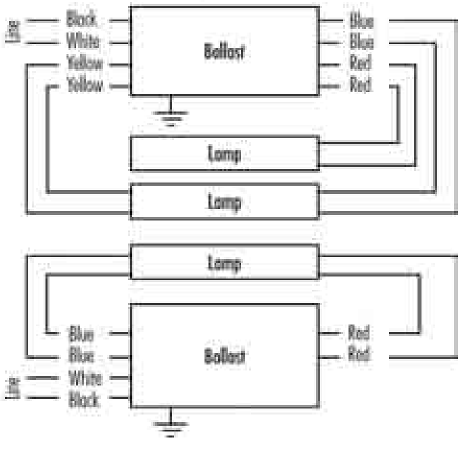
Ballast Construction

- A simple standard ballast is a core and coil assembly.
- The core is made of laminated transformer steel.
- The coil consists of copper or aluminum wire which is wound around the core.
- The core-coil assembly is impregnated with a nonconductor to provide electrical insulation and aid in heat dissipation.
- Capacitors may be included in the ballast circuit to assist in providing sufficient voltage, start the lamp, and/or correct power factor.
- Some ballasts are housed inside the lighting fixture.

Simple Ballast Illustrations



Typical Wiring Diagrams



Ballast Losses

- A ballast, as an electric circuit, has electric energy losses.
- Ballast losses are obtained from catalogues of ballast manufacturers.
- Energy efficient ballasts have lower losses.

Types

- Basic types of ballasts based on ballast construction and efficiency are:
- energy efficient ballasts (core-coil magnetic);
- electronic ballasts (solid-state);
- standard magnetic ballast (core-coil design).
- Ballasts are also classified by the type and function of their electric circuit.
- Note that electro-magnetic fluorescent ballasts are gradually being removed from the market place by energy regulations.
- Each ballast is designed to be used with a specific type and size (wattage) of lamp.
- The lamp type and size compatible with the ballast are listed on the ballast label.

Standards

- Ballasts should meet ANSI (American National Standards Institute) specifications for proper lamp performance. The Canadian standard for ballast efficiency is CAN/CSA-C654-M91 Fluorescent Lamp Ballast Efficacy Measurements.
- The CBMA (Certified Ballast Manufacturers Association) label indicates that the ballast has been tested and meets ANSI specifications.
- The UL (Underwriters Laboratories) label indicates that the ballast has been tested and meets UL safety criteria (US standard) as well as the Canadian CAN/CSA-C654-M91 criteria.
- The CSA (Canadian Standards Association) label indicates that the ballast has been tested and meets CSA safety criteria.
- Under the North American Free Trade Agreement, both UL and CSA can certify electrical products for sale in both countries.

Thermal Protection

- The NEC (US National Electrical Code) and the Canadian Electrical Code require that all indoor ballasts must be thermally protected.
- This is accomplished by a thermal switch in the ballast which turns power off above a maximum temperature (1050˚C approximately).
- Ballasts meeting this standard for protection are designated Class P.
- A cycling ballast, which turns power off and on, indicates an overheating problem.

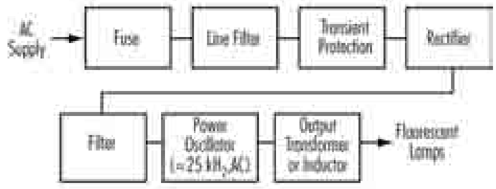
Sound Ratings

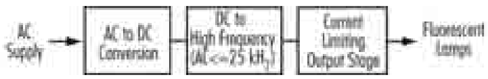
- All core-coil ballasts produce a sound commonly described as a “hum”.
- Manufacturers give the ballasts a sound rating from A to F
- An A ballast produces the least hum, and should be used in quiet areas (offices, homes).
- An F ballast produces the most audible hum, and may be used in places where noise is acceptable (factories, outdoors).

Ballast Life

- Most ballasts are designed for about 50,000 hours under standard conditions.
- If ballast and lamp heat is not dissipated properly ballast life is reduced.
- An 8-10˚C increase over rated temperature on the case will cut ballast life in half.
- Ballasts are rated typically for 75˚C. 90˚C ballasts are a special design called “Extreme Temp”. Some manufacturers list 8˚C instead of 10˚C.
- Similarly, a 100˚C decrease will approximately double ballast life.

B. ELECTRONIC BALLASTS FOR GAS DISCHARGE LAMPS


Typical Circuit Component Diagram


Functional Block Diagram
AC Supply
AC to DC Conversion
DC to High Frequency (AC<=25 kHz)
Current Limiting Output Stage
Fluorescent Lamps

Notes

- Some ballasts have fewer components.
- Some ballasts have components to reduce total harmonic distortion, improve power factor and provide thermal protection.

General Description

- A rapid start ballast starts one or more gas discharge lamps by first heating the electrodes of the lamps to the proper electron emission temperature before initiating the arc.
- An instant start ballast does not preheat the electrodes but initiates the arc by a higher starting voltage.
- A modified start ballast starts the lamp in the same way as the rapid start ballast. It then reduces or cuts off the electrode heating voltage after the lamp arc has stabilized.
- Both types of ballast stabilize the arc by limiting the current to proper levels.
- Older technology (i.e., electromagnetic) ballasts are made of laminated cores wound with copper or aluminum wires; some have capacitors to control voltage and/or to correct power factor.
- Electromagnetic ballasts operate the lamps at line frequency, 60 Hz.
- Electronic ballasts for fluorescent lamps have electronic or solid-state components.
- Electronic ballasts operate the lamps at a high current frequency, typically from 25-50 kHz.
- Electronic ballasts in both the rapid start, instant start and ‘program start’ modes are available.
- Operation of rapid start lamps by instant start or modified start ballasts can potentially shorten lamp life if combined with other control technologies such as occupancy sensors. Refer to the ballast and lamp manufacturers’ data.
- In comparison with the electromagnetic ballast, the electronic ballast weighs less, operates at lower temperatures and at a lower noise level, and is more energy efficient, but costs more.
- It is essential to match the electrical characteristics of both lamps and ballasts.

Technical Data

- Models are available for one-lamp, two-lamp, three-lamp or four-lamp fixtures.
- Available in 120 volts, 277 volts and 347 volts. Some ballasts are now available for universal voltage, i.e., 120 V to 277 V, and less common voltages such as 240 V.
- Ballast specification is based on: number of lamps, lamp type (F32T8/841 or other) and line voltage.
- Example: two-lamp F32T8/841 120V electronic ballast.
- Some electronic ballasts are dimmable.
- The efficacy of electronic ballasts is 21% to 43% better than electromagnetic ballasts.
- Total harmonic distortion (THD) indicates the strength of electromagnetic noise generated.
- Lower ballast temperature means lower electrical losses and a smaller cooling load.

Total Harmonic Distortion

- Harmonics are frequencies that are integral multiples of the fundamental frequency.
- For a 60 Hz fundamental frequency, the second harmonic is 120 Hz, and the third is 180 Hz.
- Harmonics can be present in voltage and/or current.
- Harmonics occur whenever the wave shape is distorted from a pure sine wave.
- Electric utilities supply voltage and current very close to the sinusoidal wave form.
- If the user’s load is nonlinear, drawing short pulses of current within each sine wave cycle, the sinusoidal current wave shape will be distorted and a harmonic current will be present.
- The characteristics of the nonlinear load determine the form of the distortion, the magnitude of each harmonic and the corresponding harmonic current.
- Total current is a combination of the fundamental frequency and a contribution from each of the harmonics.
- THD in the current is the root mean square (rms) of all the harmonic currents as a percentage of the fundamental current, and is defined as follows:

$$\text{THD} = \frac{\sqrt{\text{sum of squares of rms magnitudes of all harmonics}^{*}}}{\text{rms magnitude of fundamental}} \times 100\%$$

* Does not include the fundamental.

- IEEE Standard 519-1981 refers to the Distortion Factor (DF) which equals the THD. However, THD is the preferred term in this guide as it is more descriptive.
- Most electromagnetic ballasts have THD between 18% and 35%.
- Electronic ballasts generate less than 32% THD. Most of them are below 20%. Some are below 10%.

- Due to higher efficiency, the T8 electronic ballast system typically draws 30% less current than the conventional electromagnetic ballast system.

Electromagnetic Interference (EMI) or Radio Frequency Interference (RFI)

- EMI/RFI may cause interference with communication equipment, such as radio, TV, computer.
- Fluorescent lamps energized by electromagnetic or electronic ballasts radiate EMI directly into the air.
- EMI from the lamps may feed back to the line conductors via the ballasts.
- EMI at the electronic ballast fundamental frequency and its harmonics propagate from the ballast's electronic circuits to the line conductors. This EMI may interfere with other electrical equipment on the same distribution network.
- EMI may radiate from the line conductor into the air.
- EMI may be radiated from the high frequency electronic components of the electronic ballast.
- In the US, electronic ballasts must comply with Federal Communications Commission Part 18, Subpart C, Class A for industrial and commercial applications, or Class B for residential applications. As yet no Canadian standard has been set.

Power Factor

- Power factor can be calculated by two methods:
- wattage (W), voltage (V) and current (I)
- wattage (W) and reactive power (VAR).
- If calculated correctly – the results should be the same using both methods.
- A low power factor will increase the demand component of your electricity bill for a given lighting load

Rated Average Life

- Ballasts are designed to operate for about 50,000 hours.

Assessment

- Lower ballast operating temperature reduces air-conditioning load.
- The early models had lower reliability than the present ballasts.
- When used with light sensors, dimmable electronic ballasts can reduce the lighting load by providing just the required light level, if other light sources exist.
- Similarly, an energy management and control system uses dimmable ballasts to partially shed the lighting load.

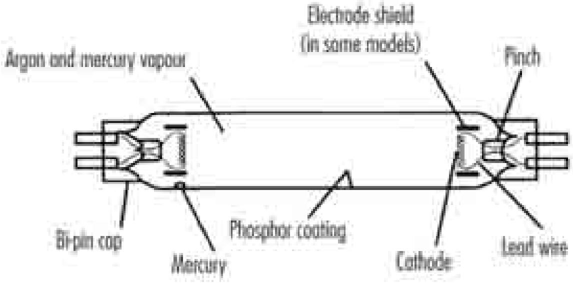
FLUORESCENT LAMPS

A. GENERAL

Construction

- For typical construction of a fluorescent lamp, see the figure below.
- A fluorescent lamp is a low-pressure mercury electric discharge lamp.
- A fluorescent lamp consists of a glass tube filled with a mixture of argon gas and mercury vapour at low pressure.
- When current flows through the ionized gas between the electrodes, it emits ultraviolet (UV) radiation from the mercury arc.
- The UV radiation is converted to visible light by a fluorescent coating on the inside of the tube.
- The lamp is connected to the power source through a ballast, which provides the necessary starting voltage and operating current.

Typical Construction of a Linear Fluorescent Lamp



Basic Types of Fluorescent Lamps

- Preheat lamps
- Instant start lamps
- Rapid start lamps

Preheat Lamps

- The cathodes of the lamp are preheated electrically for a few seconds before a high voltage is applied to start the lamp.
- The preheating is accomplished by the use of an automatic switch, called a "starter", which applies current to the cathodes for sufficient time to heat them.
- The preheat lamps have a bi-pin (double-pin) base at each end.
- Preheat lamps operate normally in a preheat circuit (preheat ballast, starter, lamp and lamp holders).
- Preheat lamps can also be used in rapid start circuits.
- Preheat lamps are not widely used today

Instant Start Lamps

- The instant start lamp requires a high starting voltage, which is supplied by the ballast.
- Since there is no preheating of the cathodes, there is no need for a starter.
- Electrode heating is provided by the arc once it has been established.
- The instant start lamps have a single-pin base at each end of the bulb.
- A few instant start lamps have bi-pin bases, with the pins connected together inside the base.
- Instant start lamps operate normally only in an instant start circuit (instant start ballast, lamp and lamp holders).

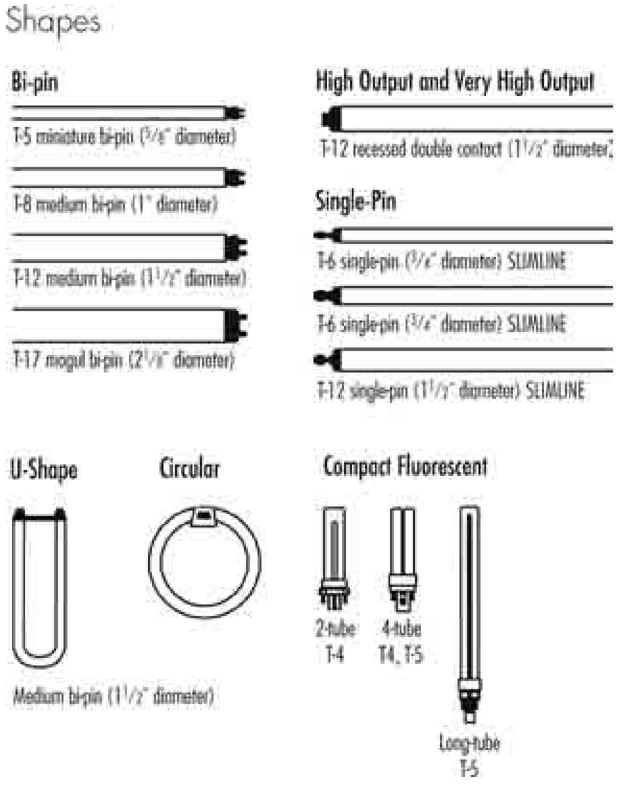
Rapid Start Lamps

- The ballast quickly heats the cathodes causing sufficient ionization in the lamp for the arc to strike.
- The cathodes may or may not be continuously heated after lamp starting, depending on ballast design.
- Rapid start lamps start almost instantly (in one or two seconds).
- No starter is required – eliminating the time delay of preheat systems.

- Less voltage is required for starting than with instant start lamps, thus using smaller, more efficient ballasts.
- The rapid start lamps have a bi-pin (double-pin) base at each end.
- Rapid start lamps can also be used for dimming and flashing applications.
- Rapid start lamps operate normally only in a rapid start circuit (rapid start ballast, lamp, and lamp holders).
- Rapid start lamps are the most widely used fluorescent lamps.

Types of Rapid Start Lamps

- Linear fluorescent lamps – new types, both T8 and T5 sizes
- Linear fluorescents (430 mA for F40) – old types, primarily T12 size
- Energy saving fluorescents, primarily T12 size
- U-shaped fluorescents, in both T8 and T12 sizes
- Circular lamps, in T9 and T5 sizes
- High output lamps, available in T12, T8 and T5 sizes
- Very high output lamps (1500 mA), primarily T12 size
- Lamp diameters range from 5/8" to 2.5"


Shapes
Bi-pin
T-5 miniature bi-pin (5/8" diameter)
T-8 medium bi-pin (1" diameter)
T-12 medium bi-pin (1 1/2" diameter)
T-17 mogul bi-pin (2 1/8" diameter)
High Output and Very High Output
T-12 recessed double contact (1 1/2" diameter)
Single-Pin
T-6 single-pin (3/4" diameter) SLIMLINE
T-6 single-pin (3/4" diameter) SLIMLINE
T-12 single-pin (1 1/2" diameter) SLIMLINE
U-Shape
Medium bi-pin (1 1/2" diameter)
Circular
Compact Fluorescent
2-tube T-4
4-tube T4, T-5
Long-tube T-5

Lamp Designations

Bi-pin lamps (preheat, instant start, rapid start)
Identified by wattage, bulb diameter and colour.

Example: F40TI2/CW/ES
F: Fluorescent lamp
40: Wattage (34 W for ES types)
T: Tubular bulb shape
12: Maximum tube diameter – in eighths of an inch (12/8 = 1.5")
CW: Cool white colour

Example: F32 T8/41K
F: Fluorescent lamp
32: Wattage (32 W)
T: Tubular bulb shape
8: Maximum tube diameter – in eighths of an inch (8 x 1/8 = 1")
41K: 4,100 K, Cool white colour

Single-pin lamps (instant start)

- Identified by length and colour rather than wattage because they can operate at more than one wattage.

Example: F96T12/WW
F: Fluorescent lamp
96: Lamp length in inches
T: Tubular bulb shape
12: Maximum tube diameter – in eighths of an inch
WW: Warm white colour

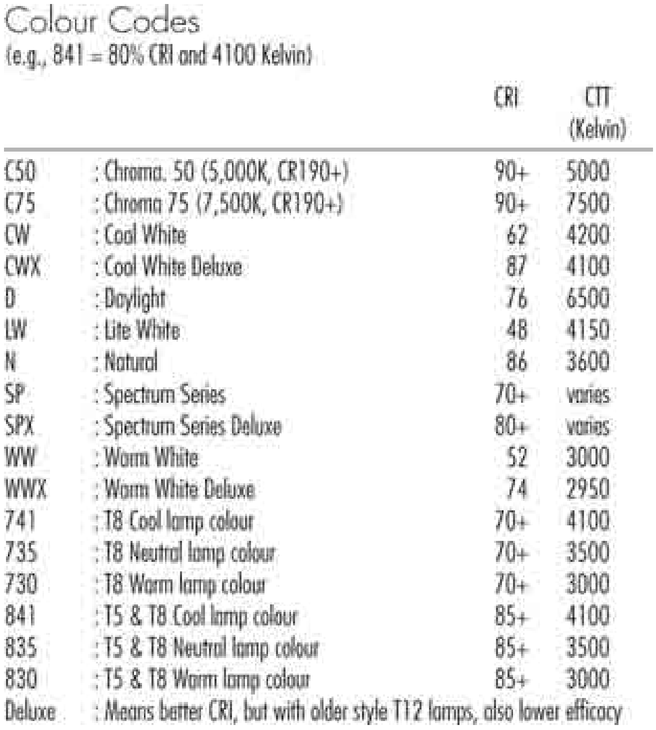
Lamp Lengths

Some typical lamp lengths are:

- F20 lamp – 24" (2')
- F30 lamp – 36" (3')
- F32 T8 lamp – 48" (4') – becoming the industry standard lamp
- F40 lamp – 48" (4')
- F96 lamp – 96" (8')

Colour Codes

(e.g., 841 = 80% CRI and 4100 Kelvin)



Colour Codes
(e.g., 841 = 80% CRI and 4100 Kelvin)

		CRI	CTT (Kelvin)
C50	: Chroma. 50 (5,000K, CR190+)	90+	5000
C75	: Chroma 75 (7,500K, CR190+)	90+	7500
CW	: Cool White	62	4200
CWX	: Cool White Deluxe	87	4100
D	: Daylight	76	6500
LW	: Lite White	48	4150
N	: Natural	86	3600
SP	: Spectrum Series	70+	varies
SPX	: Spectrum Series Deluxe	80+	varies
WW	: Warm White	52	3000
WWX	: Warm White Deluxe	74	2950
741	: T8 Cool lamp colour	70+	4100
735	: T8 Neutral lamp colour	70+	3500
730	: T8 Warm lamp colour	70+	3000
841	: T5 & T8 Cool lamp colour	85+	4100
835	: T5 & T8 Neutral lamp colour	85+	3500
830	: T5 & T8 Warm lamp colour	85+	3000
Deluxe	: Means better CRI, but with older style T12 lamps, also lower efficacy		

Lamp Type Code

The lamp type code follows the colour code.
Lamp type codes are listed below.

- IS: Instant Start
- RS: Rapid Start
- HO: High Output
- VHO: Very High Output
- U: U-shaped
- WM: WattMiser (General Electric)
- SS: Super Saver
- EW: Econowatt (Philips)

Characteristics

- General – A fluorescent luminare consists of: a ballast, usually shared by two lamps, fixture and lense or louvers
- Lamp Configuration – Linear, U-shape, circular or compact
- Lamp Watts – 7 W to 215 W
- Ballast Watts – varies according to type, electromagnetic or electronic, and Ballast Factor
- Rated Average Life – 20,000 hours for typical F32T8 lamps
  – 24,000 hour T8 lamps are available
  – 20-24 times the life of a typical incandescent
- Luminous Efficacy – 40 to 100 lumens per watt
- Lamp Lumen – 70% to 90%

Depreciation Factor (LLD)

- Colour Temperature – 2,700 K to 7,500 K
  – Wide range of colour temperatures
- Index (CRI) Colour Rendering – 62 to 94
- Warm-up Time – Instant
  – Sensitive to extremes of temperature
  – Slower than incandescent
- Restrike Time – Immediate
- Lamp Cost – Low
  – Energy-saving and energy-efficient lamps more expensive
- Main Applications – Offices, commercial

Lamp Designation	Lamp Watts	Including 1 Lamp	Ballast (2 Lamp)	Rated Lamp Life (hours)	Initial Lumens	Initial Lumens per Watt	Colour Temp Deg K	CRI
Energy Saving, Rapid Start, Bi-Pin Base F40T12/..../RS/....EW, SS or WM								
CW	34	47	(81)	20,000	2,775	59.0	4,100	62
CWX	34	47	(81)	20,000	1,925	41.0	4,100	87
WW	34	47	(81)	20,000	2,825	60.1	3,000	52
D	34	47	(81)	20,000	2,350	50.0	6,500	75
LW	34	47	(81)	20,000	2,925	62.2	4,160	48
30U	34	47	(81)	20,000	2,925	62.2	3,000	85
35U	34	47	(81)	20,000	2,925	62.2	3,500	85
41U	34	47	(81)	20,000	2,925	62.2	4,100	85
50U	34	47	(81)	20,000	2,925	62.2	5,000	85
SPEC30	34	47	(81)	20,000	2,925	62.2	3,000	70
SPEC35	34	47	(81)	20,000	2,925	62.2	3,500	73
SPEC41	34	47	(81)	20,000	2,925	62.2	4,100	70

Notes:
- Refer to lamp manufacturers for colours other than shown here.
- Rated Average Life for fluorescent lamps is based on three hours per start.
- Mean Lumens for fluorescent lamps are listed at 40% of lamp life.

See Also
- Lamp manufacturers' catalogues.

Lamp Designation	Lamp Watts	Including Ballast 1 Lamp (2 Lamp)	Rated Lamp Life (hrs)	Initial Lumens	Initial Lumens per Watt	Mean Lumens	Mean Lumens per Watt	Colour Temp Deg K	CRI	LLD
Compact Fluorescent										
7W +	7	10	10,000	400	40.0			2,700	81	0.80
9W +	9	10	10,000	600	60.0			2,700	81	0.80
13W +	13	17	10,000	900	52.9			2,700	81	0.80
Circlite (retrofit for incandescent)										
FCA22/SW +	22	22		10,000	870	39.5				
FCA44/SW +	44	44		7,500	1,750	39.8				
Rapid Start Circline										
FC8/CW/RS + 1	22	27	12,000	1,050	38.9	805	29.8	4,300	62	0.72
FC12/CW/RS +	32	44	12,000	1,800	40.9	1,465	33.3	4,300	62	0.82
FC16/CW/RS +	40	56	12,000	2,500	44.6	1,910	34.1	4,300	62	0.77
Instant Start, 200 milliamp, Single Pin Base										
F72T8/CW	38	55 (100)	7,500	3,100	56.4	2,700	49.1	4,300	62	0.83
F96T8/CW	50	70 (130)	7,500	4,200	60.0	3,860	55.1	4,300	62	0.89
Instant Start, 430 milliamp, Single Pin Base										
F48T12/CW	39	65 (104)	9,000	3,000	46.2	2,760	42.5	4,300	62	0.82
F48T12/LW	30	55 (84)	9,000	2,675	48.6	2,460	44.7	4,100	49	0.82
F72T12/CW	55	80 (150)	12,000	4,600	57.5	4,320	52.9	4,300	62	0.89
F96T12/CW	75	97 (172)	12,000	6,300	64.9	5,800	59.8	4,300	49	0.89
F96T12/LW	60	82 (142)	12,000	6.000	73.2	5,430	66.2	4,100	49	0.89
Rapid Start, 430 milliamp, Bi-pin Base										
F30T12/CW/RS	30	46 (76)	18,000	2,300	50.0	2,010	43.7	4,300	62	0.81
F40T12/.../RS										
cool white	40	53 (93)	20,000	3,150	59.4	2,715	51.2	4,300	62	0.84
cool white deluxe	40	53 (93)	20,000	2,220	41.5	1,800	34.0	4,200	87	0.84
warm white	40	53 (93)	20,000	3,200	60.4	2,715	51.2	3,000	52	0.84
warm white deluxe	40	53 (93)	20,000	2,150	40.6	1,765	33.3	3,100	73	0.84
daylight	40	53 (93)	20,000	2,600	49.1	2,245	42.4	6,500	75	0.84

Lamp Designation	Lamp Watts	Including Ballast 1 Lamp (2 Lamp)	Rated Lamp Life (hrs)	Initial Lumens	Initial Lumens per Watt	Mean Lumens	Mean Lumens per Watt	Colour Temp Deg K	CRI	LLD
lite white	35	48 (83)	20,000	3,050	63.5			4,160	48	0.84
lite white deluxe	34	47 (81)	20,000	3,050	64.9			4,100	67	0.84
full spectrum 5000	40	53 (93)	20,000	2,200	41.5	1,850	34.9	5,000	92	0.84
full spectrum 7500	40	53 (93)	20,000	2,000	37.7	1,685	31.8	7,500	94	0.84
prime colour 3000	40	53 (93)	20,000	3,400	64.2			3,000	85	0.84
prime colour 4000	40	53 (93)	20,000	3,400	64.2			4,000	85	0.84
*indicates low power factor ballast only available										
Rapid Start T8, Bi-pin Base										
F032/730	32	30 (59)	20,000	2,800	93.0	2,520	84.0	3,000	75	0.90
F032/830	32	30 (59)	20,000	2,950	98.0	2,714	90.0	3,000	82	0.92
F032/830 6		30 (59)	24,000	2,900	96.6	2,755	91.8	3,000	85	0.95
F032/830/XP		30 (59)	24,000	3,000	100	2,850	95.0	3,000	85	0.95
High Output Rapid Start, 800 milliamp, Recessed Double Contact Base										
F48T12/CW/HO	60	85 (146)	12,000	4,300	50.6	3,740	44.0	4,300	62	0.82
F72T12/CW/HO	85	106 (200)	12,000	6,650	62.7	5,785	54.6	4,300	62	0.82
F96T12/CW/HO	110	140 (252)	12,000	9,200	65.7	8,005	57.2	4,300	62	0.82
F96T12/LW/HO	95	119 (231)	12,000	9,100	76.5	7,915	66.5	4,160	48	0.82
F96T12/LWX/HO	95	119 (231)	12,000	9,100	76.5			4,100	67	0.82
Very High Output Rapid Start, 1500 milliamp, Recessed Double Contact Base										
F48T12/CW/VHO	110	146 (252)	10,000	6,250	42.8	4,750	32.5	4,300	62	0.69
F72T12/CW/VHO	165	213 (326)	10,000	9,900	46.5	7,920	37.2	4,300	62	0.72
F96T12/CW/VHO	215	260 (450)	10,000	14,500	55.8	11,600	44.6	4,300	62	0.72
F96PG17/CW	215	260 (450)	12,000	16,000	61.5	12,800	49.2	4,300	62	0.69
F96PG17/LW	185	230 (390)	12,000	14,900	64.8	11,325	49.2	4,160	48	0.69

*indicates low power factor ballast only available

Notes: Some lamps listed here are no longer commercially available, notably the full output F40/CW lamp; they are included here for comparison only.

B. PREMIUM T-8 LAMPS

Lamp manufacturers now offer premium grade T-8 lamps for special applications where exceptional colour, longer life and improved lumen output are required.

Standard F32 T-8 Lamp:
- 20,000 hrs, 82 CRI, 2,950 initial lumens, 98.3 initial lm/W

Premium F32 T-8 Lamp:
- 30,000 hrs, 86 CRI, 3,100 initial lumens, 103.3 initial lm/W

C. LOW-WATTAGE T-8 LAMPS

Lamp manufacturers now offer reduced output or low-wattage T-8 lamps for increased savings on retrofit projects, or for new construction.

Standard F32 T-8 Lamp:
- 20,000 hrs, 82 CRI, 2,950 initial lumens, up to 80 lm/W depending on ballast

Low-Wattage F28 T-8 Lamp:
- 24,000 hrs, 82 CRI, 2,562 initial lumens, up to 93 lm/W, depending on ballast
- These lamps have some limitations, for example, they cannot be dimmed, and don't operate in cool temperatures (<60˚F)
- Some operate on programmed start ballasts and all operate in instant start ballasts.

D. T-5 AND T5-HO FLUORESCENT LAMPS

- Lamp manufacturers now offer T-5 fluorescent lamps in both standard and High Output (HO) versions.
- The smaller diameter tube yields a more compact lumen package, which is easier to control.
- T-5 fluorescent lamps are available in various lengths and wattages from 14 W to 80 W, and in a circline version in 22 W, 40 W, and 55 W.
- T-5 lamps are nominal length lamps, which means that they cannot be retrofit into fixtures using standard T-12 or T-8 lamps. Therefore, they are generally used for re-design or new construction projects.
- T-5 fluorescent lamps require the use of electronic ballasts and unique sockets.
- T-5 lamps are driving miniaturization and can be used in indirect applications.
- T5-HO is an increasingly popular fluorescent lamp; primarily used in normal to high bay applications, big box retail, warehouse and distribution centres, industrial applications and gymnasiums. T5-HO are also dimmable and operate on instant start ballasts.
- T5 and T5-HO have maximum light output at higher ambient temperatures.

Standard T-5 Lamps:
- 14 W, 24" (nom), 20,000 hrs, 82 CRI, 1,350 initial lumens
- 21 W, 36" (nom), 20,000 hrs, 82 CRI, 2, 100 initial lumens
- 28 W, 48" (nom), 20,000 hrs, 82 CRI, 2,900 initial lumens
- 35 W, 60" (nom), 20,000 hrs, 82 CRI, 3,650 initial lumens

High Output T-5 Lamps:
- 24 W, 24" (nom), 20,000 hrs, 82 CRI, 2,000 initial lumens
- 39 W, 36" (nom), 20,000 hrs, 82 CRI, 3,500 initial lumens
- 54 W, 48" (nom), 20,000 hrs, 82 CRI, 5,000 initial lumens

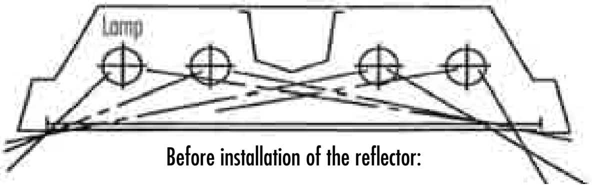
E. FLUORESCENT FIXTURE REFLECTORS

General Description

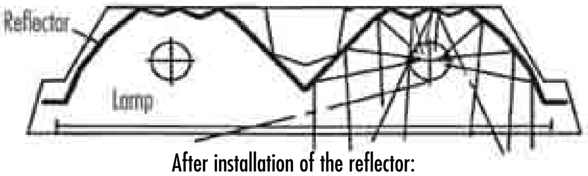
Fluorescent fixture reflectors are sheets of aluminum placed inside fluorescent fixtures, which divert light directed toward the ceiling down toward the work area.

Illustration

- Illustration of a recessed reflector for a 2' x 4' fixture, with removal of two lamps.



Before installation of the reflector:



After installation of the reflector:

Physical Data

- There are three basic types of reflectors:
- Anodized aluminum or steel reflectors – in which the surface is painted with a highly reflective electrostatic or powder-epoxy finish.
- Anodized aluminum reflectors – in which the aluminum surface is treated (polished) electrochemically.
- Silver film reflectors – in which a thin film of silver is laminated to an aluminum substrate.
- The reflector finish can be high gloss paint, specular (mirror-like), semi-specular, or diffuse (matt).
- The reflector shape is specially designed to optimize light distribution (custom-designed by the supplier).
- Reflectors are made in the following sizes:
- Single reflectors – 4' or 8' long, one-lamp use
- Double reflectors – 4' or 8' long, two-lamp use
- Recessed reflectors – for 2' x 2' or 2' x 4' fixtures.

Technical Data

- The average total reflectivity for anodized aluminum reflectors is about 90% to 91%.
- The average total reflectivity for silver film reflectors is about 94% to 97%.
- Life expectancy of a silver film reflector is about 15 years.
- Life expectancy of an anodized aluminum reflector is about 20 years.

Applications

- Reflectors are used for lighting energy conservation.
- Reflectors are used for fixture retrofitting or in new energy efficient fixtures.
- A typical application is the installation of a recessed reflector in a 2' x 4' fixture, with removal of two of the four tubes.

- In most instances, it is necessary to re-centre the two remaining lamps in the fixture to avoid dark spots.
- The reflector creates the image of a lamp in the place of the removed lamp; this allows delamping without creating dark spots.
- The light output of a retrofitted fixture with half the lamps removed typically decreases by about 35%, depending on reflector material and design.
- Cleaning and relamping at the same time increases light output by 5% to 20%.

Costs

- Costs depend on the type, size and design of the reflector.

Advantages

- Reduces lighting power consumption;
- Improves luminous efficacy in the work area;
- Reduces cooling load, in the case of delamping;
- Extends ballast and lamp life by decreasing operating temperature;
- Fewer lamps and fixtures are required;
- Reduces maintenance costs.

Disadvantages

- May have long payback period;
- Not cost-effective if fixtures of different size and type are involved;
- May create a ‘cave effect’ in some situations, causing walls to appear dark at the top because the light is focused downwards.

Assessment

- Has clear benefits from a lighting efficiency point of view.
- Should be compared to other lighting conservation measures.

F. COMPACT FLUORESCENT LAMPS

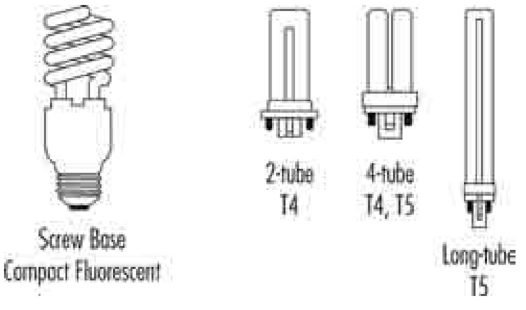
Introduction

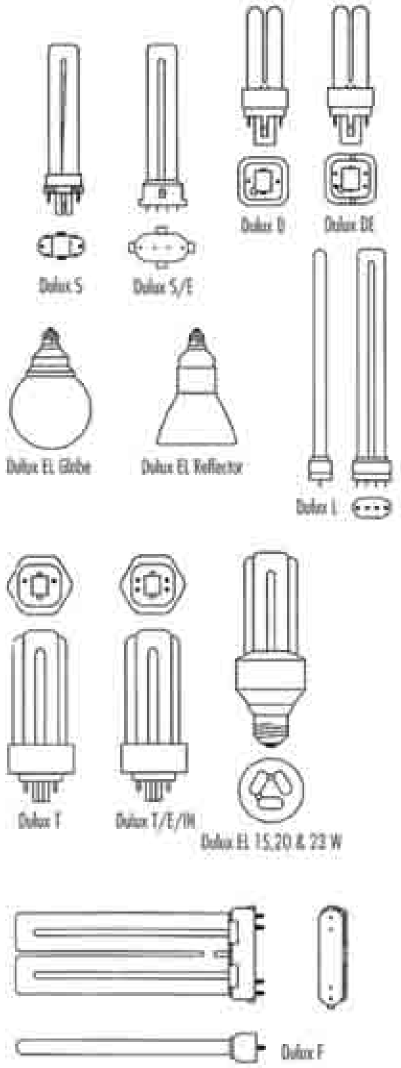
- Compact fluorescent lamps are small-size fluorescent lamps.

Types

There are two general types of lamps:

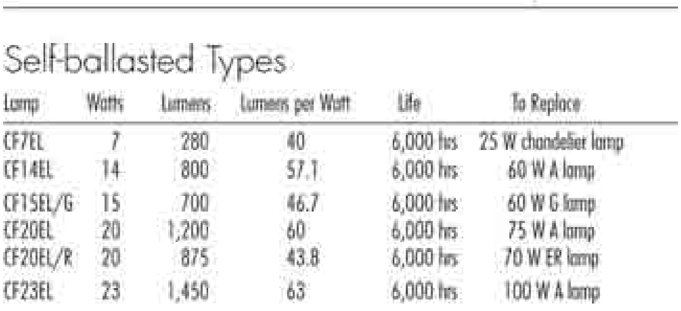
- self-ballasted or screw based lamps, for direct replacement of incandescent lamps
- pin-based lamps for compact fluorescent light fixtures
- They are also available in a large variety of sizes and wattages, and in twin-tube, quad-tube, long tube, twisted, reflectorized and fully enclosed versions.





Shapes

Lamp	Magnetic Ballast System Watts	Lumens	Lumens per Watt	Length (mm)	Length (in.)	Colour Temp K	CRI	Life	Base
2-tube or Bi-tube									
5 W	8 W	250	50	105	4 1/8	2700	82	10,000	G23
7 W	10 W	400	57	135	5 5/16	2700	82	10,000	G23
9 W	12 W	600	67	167	6 9/16	2700	82	10,000	G23
13 W	17 W	900	69	178	7 1/2	2700	82	10,000	G23
4-tube or Quad-tube									
10 W	14 W	600	60	108	4 1/4	2700	82	10,000	G24D-1
13 W	17 W	900	69	140	5 5/8	2700	82	10,000	G24D-1
18 W	23 W	1,250	69	170	6 7/8	2700	82	10,000	G24D-2
26W	32 W	1,800	69	190	7 1/2	2700	82	10,000	G24D-3
Long-tube or High Output									
18W	25 W	1,250	69	221	8 11/16	2700	82	10,000	2G11
						3000	82	10,000	2G11
						4000	82	10,000	2G11
24 W	32 W	1,900	79	320	12 9/16	2700	82	10,000	2G11
						3000	82	10,000	2G11
						4000	82	10,000	2G11
36 W	48 W	3,000	83	417	16 7/8	2700	82	10,000	2G11
						3000	82	10,000	2G11
						4000	82	10,000	2G11



Self-ballasted Types

Lamp	Watts	Lumens	Lumens per Watt	Life	To Replace
CF7EL	7	280	40	6,000 hrs	25 W chandelier lamp
CF14EL	14	800	57.1	6,000 hrs	60 W A lamp
CF15EL/G	15	700	46.7	6,000 hrs	60 W G lamp
CF20EL	20	1,200	60	6,000 hrs	75 W A lamp
CF20EL/R	20	875	43.8	6,000 hrs	70 W ER lamp
CF23EL	23	1,450	63	6,000 hrs	100 W A lamp

General Remarks

- The self-ballasted (screw base) lamps are available with incandescent-like features (small size, shape, dimming, 3-way, etc.)
- Compact fluorescent lamps are about four times more efficient than standard incandescent lamps.
- Efficacy or lamp efficiency increases with lamp size and wattage. The smaller size, lower wattage lamps are generally less efficient than the larger size and higher wattage lamps.
- Compact fluorescents have an average life that is 10 times longer than that of standard incandescent lamps, and have a lower maintenance costs.
- They have a high colour rendering index, generally >82, but lower than incandescent lamps.
- They need a ballast to operate, as do all fluorescent lamps.
- Lamps of different manufacturers are interchangeable.
- Maximum overall length
- Most compact fluorescent lamps are available with a variety of colour temperature values, similar to T5 and T8 fluorescent lamps (3,000 K, 3,500 K, 4,100 K).
- There is an Energy Star program for compact fluorescent lamps in North America.

Compact Fluorescent Fixtures

- Many manufacturers produce fixtures for compact fluorescent lamps which include a specially designed ballast and socket (lamp holder). These are available in recessed, outdoor and decorative versions.
- Lamp manufacturers produce retrofit adapters which include the ballast and lamp socket, and have a base to screw directly into a standard incandescent socket (see Self-Ballasted Types, above.).
- Recessed compact fluorescent fixtures should have a properly designed reflector, otherwise light will be trapped inside the fixtures and be wasted.

Two-tube Compact Fluorescent Lamps

- Can be used as replacements for small incandescent lamps.
- Compact fluorescent lamp sizes 5 W, 7 W, 9 W and 13 W can replace incandescent lamp sizes 25 W, 40 W, 50 W and 60 W respectively.
- Compact fluorescent lamps of different wattage rating use slightly different bases and sockets, to eliminate the possibility of plugging a lamp into a fixture with the wrong ballast for that lamp. For example, it is not possible to plug a 13 W lamp into the socket of a fixture with a ballast rated for a 26 W lamp.

Applications

- Lobby areas, hallways and corridors, any area where there are long hours of use.
- Recessed downlight fixtures.
- Wall and ceiling-mounted fixtures.
- Directional signs.
- Security lighting fixtures.
- Desk and task lighting fixtures.
- Display lighting (museums, stores).
- To replace light bulbs in fixtures which are not readily accessible.

Four-Tube Compact Fluorescent Lamps

- Made by combining two two-tube compact fluorescent lamps.
- Also known as double twin-tubes, quad or cluster lamps.
- Same length as two-tube compacts, but double the light output (lumens).
- Four-tube compact fluorescent lamp sizes 9 W, 13 W, 22 W and 28 W can replace incandescent lamp sizes 40 W, 60 W, 75 W and 100 W respectively.

Applications

- Similar to the applications of the two-tube compact fluorescent lamp (see above).
- The four-tube compact fluorescent lamps replace relatively higher wattage incandescent lamps than the two-tube compacts.

Long Tube Compact Fluorescent Lamps

- Longer than the two-tube and four-tube compact fluorescent lamps.
- Can replace standard fluorescent lamps.
- Long tube compact fluorescent lamp sizes 18 W, 24 W and 36 W have the same light output as standard fluorescents F20, F30 and F40 respectively, but are only one third of the length.
- Longer compact fluorescent lamps also feature longer lamp life, up to 20,000 hrs.

HID LAMP BALLASTS

A. BALLASTS GENERAL

Like fluorescent lamps, HID lamps are electric discharge lamps. A ballast is required to provide proper starting and operating voltage and current in order to initiate and sustain the arc.

B. PROBE START BALLASTS

The standard core and coil HID ballast or probe start ballast consists of a series of electrical coils on a core of steel laminations. The coils are impregnated with a varnish to provide electrical insulation, reduce noise and dissipate heat.

Some ballasts for interior use are housed in metal cans and potted with insulating materials.

C. PULSE START BALLASTS

- Pulse start HID Ballasts incorporate a different starting technique which reduces ballast losses and increases lamp performance.
- Pulse start retrofits can be a good measure for existing metal halide installations in schools, industrial and commercial projects.

- A 320 W metal halide pulse start system can replace a 400 W system.
- The pulse start lamp gives less lamp lumen depreciation, better colour consistency over lamp life, and faster hot restrike.

D. ELECTRONIC HID BALLASTS

Designed primarily for the low wattage Ceramic Metal Halide lamps, the electronic HID ballasts are gradually expanding to higher lamp wattages.

Advantages

- Significantly smaller size and lower weight than core and coil systems.
- More efficient, up to 20% savings over conventional ballasts.
- Square wave output increases lamp life.
- Automatic end-of-life detection; shuts lamp down instead of trying to restart.

HID LAMPS & LPS LAMPS

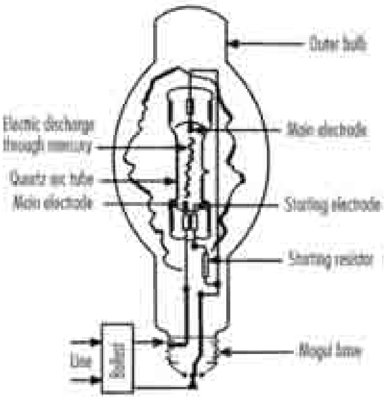
A. MERCURY VAPOUR (MV) LAMPS

Note:

Use of MV Lamps should be discouraged. They are no more efficient than fluorescent applications in indoor applications. In outdoor applications they should be replaced with one of the other gas discharge lamps. The disposal of mercury vapour lamps requires special methods because of the mercury inside the lamp. Local disposal authorities should be contacted for approved disposal methods.

Construction

- The mercury vapour (MV) lamp, or mercury lamp, is a high-intensity discharge (HID) lamp.
- Light is produced by current passing through the mercury vapour at relatively high pressure.
- The MV lamp is the oldest HID source.
- An MV lamp, like all HID lamps, consists of an arc tube enclosed in an outer bulb (a bulb in a bulb).
- The arc tube contains the mercury vapour, a starting gas (argon) and the electrodes.
- The outer bulb contains an inert gas (nitrogen) to prevent oxidation of internal parts and to maintain the operating temperature.
- The outer bulb also provides an inner surface for an optional phosphor coating.



Typical Construction and Circuit of an MV Lamp

Operation

- When the lamp is turned on, a voltage is applied to initiate an arc between a starting electrode and the nearby main electrode, which vaporizes the mercury.
- The "warm-up" time until the lamp develops full light output is five to seven minutes.
- The "restrike" time (time required to start up after a momentary power interruption) is about 10 minutes.
- During operation, when the electric arc is formed the mercury vapour emits light and ultraviolet (UV) radiation.
- UV radiation can be converted to light by a phosphor coating on the inside of the outer bulb.
- MV lamps, like all HID lamps, require ballasts.

Sizes

- Standard MV, 40 to 1,000 watts.
- Self-ballasted MV, 160 to 1,250 watts.

Rated Average Life

- 24,000 hours + for most MV lamps.

Colour

- There are two types of MV lamps, clear and phosphor-coated.
- Clear MV lamps have a bluish-white colour and poor colour rendering.
- Phosphor-coated MV lamps have a better colour appearance and colour rendering.

Efficacy

- MV lamps are the least efficient of all HID lamps.
- MV lamps are more efficient than incandescent lamps, but less efficient than fluorescent lamps.
- Efficacies range from 10 to 63 lumens per watt.

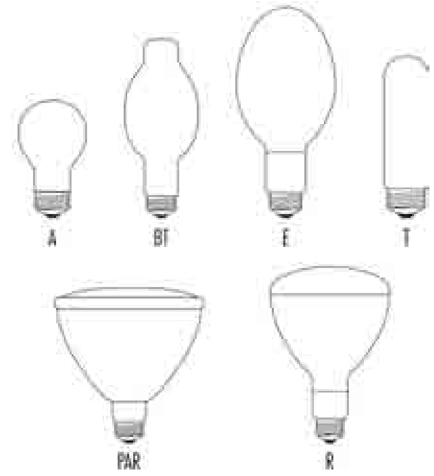
Applications

- MV lamps are no longer specified for new construction or retrofit due to poor efficacy.
- The disposal of mercury vapour lamps will require special disposal methods because of the mercury inside the lamp. Local disposal authorities should be contacted for approved disposal methods
- Interior industrial applications.
- Street lighting, security lighting, floodlighting.
- Retail shops, indoor shopping malls, restaurants, cafeterias, air/bus terminals, lobbies, foyers, gymnasiums, banks, barns.

MV vs Other High Intensity Discharge Lamps

- It may be more economical to replace MV lamps with metal halide or high pressure sodium (HPS) lamps, which have much better luminous efficacy.
- These direct replacement lamps may improve the efficacy by 70%+.
- Refer to chapters on MH lamps and HPS lamps
- MV lamps are rarely used in new lighting systems.

Shapes



Shape code

A: Arbitrary reflector	PAR: Parabolic aluminized
BT: Bulged-tubular	R: Reflector
E: Elliptical	T: Tubular

Lamp Data

Lamp Designation	Lamp Watts	Including Ballast 1 Lamp (2 Lamp)	Rated Lamp Life (hrs)	Initial Lumens	Initial Lumens per Watt	Lumens Mean Lumens	Mean Colour per Watt	Temp Deg K	CRI	LLD
Clear										
H43 75	75	95 (190)	24,000	2,800	29.5	2,430	25.6	7,000	22	0.73
H38 100	100	125 (250)	24,000	4,100	32.8	3,380	27.0	7,000	22	0.78
H42 125	125	155 (310)	24,000	5,700	36.8	5,020	32.4	7,000	22	0.88
H39 175	175	210 (410)	24,000	7,900	37.6	7,400	352	6,800	22	0.88
H37 250	250	290 (580)	24,000	12,000	41.4	10,800	37.2	5,900	22	0.81
H33 400	400	450 (880)	24,000	20,500	45.6	18,700	41.6	5,900	22	0.84
H35 700	700	775 (1,550)	24,000	41,000	52.9	37,300	48.1	5,900	22	0.81
H36 1000	1,000	1,100 (2,200)	24,000	57,500	52.3	50,600	46.0	5,900	22	0.78
Phosphor Coated										
H46 50/DX	50	63 (125)	16,000	1,575	25.0	1,260	20.0	4,000	43	0.61
H43 75/DX	75	95 (190)	16,000	2,800	29.5	2,250	23.7	4,000	43	0.72
H38 100/DX	100	125 (250)	24,000	4,200	33.6	3,530	28.2	4,000	43	0.70
H42 123/DX	125	155 (310)	24,000	6,350	41.0	5,270	34.0	4,000	43	0.76
H39 175/DX	175	210 (410)	24,000	8,600	41.0	7,650	36.4	4,000	43	0.70
H37 250/DX	250	290 (580)	24,000	13,000	44.8	11,000	37.9	4,000	43	0.62
H33 400/DX	400	450 (880)	24,000	23,000	51.1	18,400	40.9	4,000	43	0.70
H35 700/DX	700	775 (1,550)	24,000	44,500	57.4	34,500	44.5	4,000	43	0.64
H36 1000/DX	1,000	1,100 (2,200)	24,000	63,000	57.3	47,500	43.2	4,000	43	0.65
Self-Ballasted (for replacement of incandescent)										
H160	160	160	12,000	2,300	14.4	1,600	10.0			
H250	250	250	12,000	5,000	20.0	3,750	15.0			
H450	450	450	16,000	9,500	21.1	7,125	15.8			
H750	750	750	16,000	14,000	18.7	10,500	14.0			

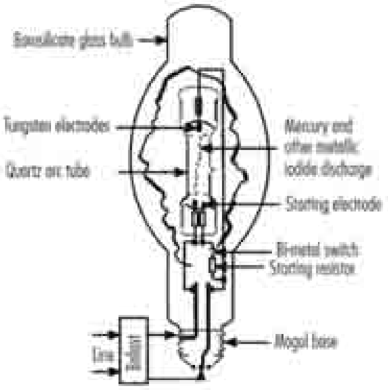
Notes:
- Mounting for position-oriented lamps is indicated as HOR (horizontal) or VER (vertical) only.
- When position is unspecified the lumen output value given applies to vertical mounting. Slightly reduced values will result if lamp is mounted in other positions.
- Life and mean lumen ratings for HID lamps are based on 10 hours per start.
- H indicates MV lamp (H for Hg - the chemical symbol for mercury).
- These lamps are being phased out.

B. METAL HALIDE LAMPS

Construction

- The metal halide (MH) lamps are generally similar in construction to the MV lamps.
- They operate on the same principle as all HID lamps.
- The main difference is that the arc tube contains metallic salts (scandium and sodium) in addition to the mercury vapour and argon gas.
- Like all HID sources, MH lamps consist of an arc tube enclosed in an outer bulb.

Typical Construction and Circuit of an MH Lamp



Note: Pulse Start lamp uses higher open circuit voltage for starting.

Operation

- Warm-up time is about 4 minutes.
- Restrike time is about 10-12 minutes standard – 4-7 min. for pulse start.
- MH lamps generally cannot be burnt in any position.
- Horizontal-burning lamps have the arc tube bowed upward, to follow the natural curve of the arc stream in the horizontal burning position.

Available Wattage

- Sizes range from 40 to 1,500 watts.

Rated Average Life

- 6,000 hours (70 W) to 20,000 (400 W).

Colour

- MH lamps are available in both clear and phosphor-coated versions.
- Clear lamps produce a slightly bluish-white colour and have a CRI far superior to MV lamps.
- Phosphor-coated lamps produce a warmer-looking white light and an improved CRI.
- MH lamps exhibit some colour variation from lamp to lamp and normally change colour throughout their life.

Efficacy

- The MH lamp is the most efficient source of “white” light available.
- Efficacies range from 50 to 110 lumens per watt.
- MH lamps are more efficient than MV and fluorescent lamps, but less efficient than HPS and low pressure sodium (LPS) lamps.
- CRI – 65-70

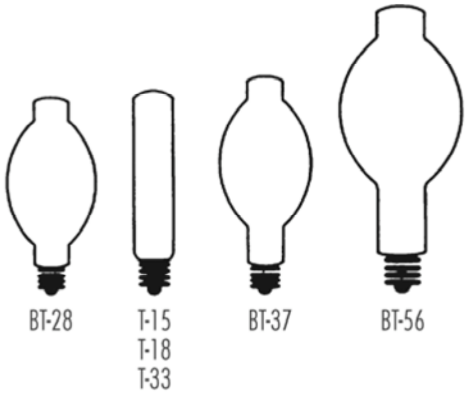
Applications

- Similar to MV lamps.
- MH lamps are effective replacements for MV lamps.
- Large wattages are used for floodlighting, streetlighting, large industrial areas and sports arenas.
- Smaller wattages are used in merchandising areas, assembly spaces, schools and public buildings.
- Clear lamps are used for colour TV broadcasting, colour photography, industrial/commercial lighting.
- Phosphor-coated lamps are used for industrial/commercial indoor lighting, area lighting.

Brands

Major manufacturers carry a variety of metal halide lamps.

Shapes



BT: Bulged-tubular T: Tubular
Numbers indicate maximum diameter in eighths of an inch.

MH Lamps Safety

- Fixtures with MH lamps should be fully enclosed.
- MH and MV lamps operate under high pressure and very high temperatures and there is a possibility that the arc tube may rupture.
- When this happens, the outer bulb surrounding the arc tube may break, and particles of extremely hot quartz (from the arc tube) and glass fragments (from the outer bulb) create a risk of personal injury or fire.
- Sylvania and General Electric have issued warnings to the users of their MH lamps.

Sylvania's warning:

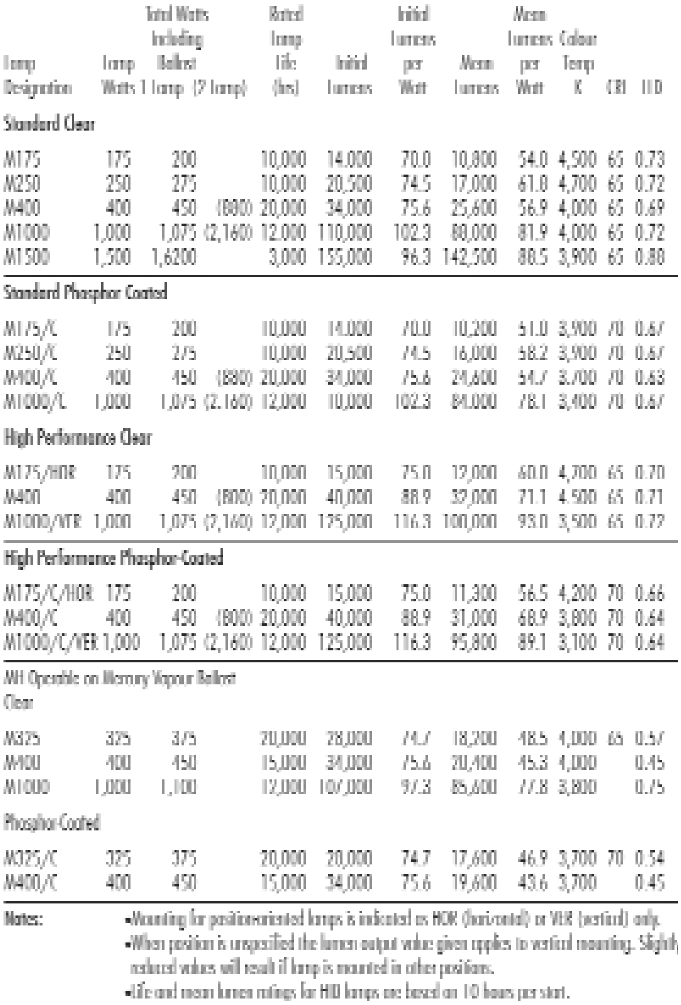
- All MH lamps should be used in enclosed fixtures.
- Enclosures must be made of suitable material, such as tempered glass.

General Electric's warning:

- All MH lamps in horizontal, or more than 15% off-vertical position, should be used in enclosed fixtures.
- 175 W, 250 W, 1500 W MH lamps, regardless of position, should be used in enclosed fixtures.
- 325 W, 400 W, 950 W, 1000 W MH lamps, in vertical position, or less than 15% off-vertical position, can be used in open fixtures.
- In continuously operating systems, turn the lamps off once a week for at least 15 minutes.
- MH lamps near the end of their life may not start.
- Relamp fixtures at or before end of rated life.

Direct Replacement of MV Lamps

- Some MH lamps are designed as direct replacements for MV lamps and use the existing MV lamp fixtures and ballasts.
- In comparison with the MV lamps, the efficacy may be improved by 70%+, but the rated average life is generally shorter.
- An energy conservation retrofit.



Lamp Designation	Lamp Watts	Total Watts Including Ballast 1 Lamp	(2 Lamp)	Rated Lamp Life (hrs)	Initial Lumens	Initial Lumens per Watt	Mean Lumens	Mean Lumens per Watt	Colour Temp K	CRI	LLD
Standard Clear											
M175	175	200		10,000	14,000	70.0	10,800	54.0	4,500	65	0.73
M250	250	275		10,000	20,500	74.5	17,000	61.8	4,700	65	0.72
M400	400	450	(800)	20,000	34,000	75.6	25,600	56.9	4,000	65	0.69
M1000	1,000	1,075	(2,160)	12,000	110,000	102.3	88,000	81.9	4,000	65	0.72
M1500	1,500	1,6200		3,000	155,000	96.3	142,500	88.5	3,900	65	0.88
Standard Phosphor Coated											
M175/C	175	200		10,000	14,000	70.0	10,200	51.0	3,900	70	0.67
M250/C	250	275		10,000	20,500	74.5	16,000	58.2	3,900	70	0.67
M400/C	400	450	(800)	20,000	34,000	75.6	24,600	54.7	3,700	70	0.63
M1000/C	1,000	1,075	(2,160)	12,000	10,000	102.3	84,000	78.1	3,400	70	0.67
High Performance Clear											
M175/HOR	175	200		10,000	15,000	75.0	12,000	60.0	4,700	65	0.70
M400	400	450	(800)	20,000	40,000	88.9	32,000	71.1	4,500	65	0.71
M1000/VER	1,000	1,075	(2,160)	12,000	125,000	116.3	100,000	93.0	3,500	65	0.77
High Performance Phosphor-Coated											
M175/C/HOR	175	200		10,000	15,000	75.0	11,300	56.5	4,200	70	0.66
M400/C	400	450	(800)	20,000	40,000	88.9	31,000	68.9	3,800	70	0.64
M1000/C/VER	1,000	1,075	(2,160)	12,000	125,000	116.3	95,800	89.1	3,100	70	0.64
MH Operable on Mercury Vapour Ballast											
Clear											
M325	325	375		20,000	28,000	74.7	18,200	48.5	4,000	65	0.57
M400	400	450		15,000	34,000	75.6	20,400	45.3	4,000		0.45
M1000	1,000	1,100		12,000	107,000	97.3	85,600	77.8	3,800		0.75
Phosphor-Coated											
M325/C	325	375		20,000	20,000	74.7	17,600	46.9	3,700	70	0.54
M400/C	400	450		15,000	34,000	75.6	19,600	43.6	3,700		0.45

Notes:
- Mounting for position-oriented lamps is indicated as HOR (horizontal) or VER (vertical) only.
- When position is unspecified the lumen output value given applies to vertical mounting. Slightly reduced values will result if lamp is mounted in other positions.
- Life and mean lumen ratings for HID lamps are based on 10 hours per start.

CERAMIC METAL HALIDE LAMPS

General Description

- In order to counter the poor colour consistency of metal halide lamps over life, lamp manufacturers have combined the ceramic arc tube from HPS lamps with the gas mix and metals used in Metal Halide lamps to produce Ceramic Metal Halide (CMH) lamps.
- These lamps offer significant advantages over typical Metal Halide lamps and are available in PAR packages to fit smaller recessed and track-mounted luminaires.
- These sources and luminaires offer significant savings compared to incandescent lamps typically used in retail (stores) and display lighting.

Comparison

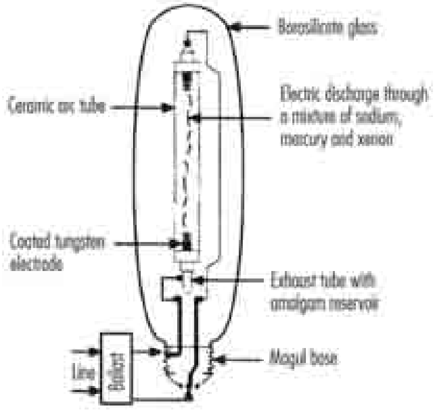
120 W Halogen PAR 38 Flood:
25°, 3,000 hrs, 7,700 MBCP, 1,800 lm, 95 CRI
39 W CMH PAR 30 Flood (55W with electronic ballast):
30°, 9,000 hrs, 7,400 MBCP, 2,300 lm, 85 CRI

C. HIGH PRESSURE SODIUM LAMPS

Construction

- High pressure sodium (HPS) lamps are HID lamps that ionize sodium vapour.
- Like all HID sources, HPS lamps consist of an arc tube enclosed in an outer bulb.
- The arc tube contains xenon (starting gas), sodium and mercury.
- The mercury is in the form of an amalgam with the sodium.
- HPS lamps do not have starting electrodes because of the arc tube's small diameter.
- The arc tube is made of a ceramic that can withstand high temperatures (1,300°C) and resist the corrosive effects of hot sodium.

Typical Construction and Circuit of an HPS Lamp


Borosilicate glass
Ceramic arc tube
Electric discharge through a mixture of sodium, mercury and xenon
Coated tungsten electrode
Exhaust tube with amalgam reservoir
Line
Ballast
Mogul base

Operation

- The ballast provides a high-voltage pulse (2,500 V) for one microsecond for lamp start.
- This high-voltage spike establishes the xenon arc between the main electrodes.
- Mercury and sodium then vaporize rapidly and maintain the arc.
- Warm-up time is three to four minutes.
- Restrike time is about one minute – shortest restrike time of all HID sources.

Sizes

- HPS lamp sizes range from 35 to 1,000 watts.

Rated Average Life

- 24,000 hours for most HPS lamps.

Colour

- The light colour of HPS lamps is usually described as golden-white.
- HPS lamps are available in either clear or diffuse-coated versions.
- Improved colour lamps operating under increased pressure have better colour rendering properties at the expense of lamp life and luminous efficiency.

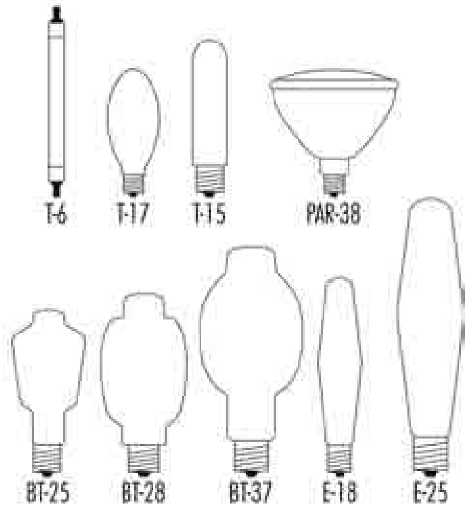
Efficacy

- HPS lamps are the most efficient source of golden-white light.
- HPS lamps are more efficient than MH lamps, but less efficient than Low Pressure Sodium (LPS) lamps.
- Efficacies range approximately from 50 to 140 lumens per watt.
- Efficacy increases with lamp size.

Applications

- All applications where colour is less important.
- Clear lamps are used in roadway lighting, floodlighting, industrial lighting, area lighting, airport lighting.
- Coated lamps are used in area and floodlighting, security lighting, industrial and commercial indoor lighting and parking lots.

Shapes



Shape Codes
B : Bullet
BT : Bulged-tubular
E : Elliptical
PAR : Parabolic aluminized reflector
T : Tubular
Numbers indicate approximate maximum diameter, in eighths of an inch.

Lamp Designation	Lamp Watts	Total Watts Incl. Ballast 1 Lamp	Rated Lamp Life (hrs)	Initial Lumens	Initial Lumens per Watt	Mean Lumen	Mean Lumens per Watt	Colour Temp Deg K	CRI	LLD
Clear										
S 35	35	55	16,000	2,250	40.9	2,025	36.8	1,900	21	0.84
S 50	50	70	24,000	4,000	57.1	3,600	51.4	1,900	21	0.81
S 70	70	95	24,000	5,800	61.1	5,220	54.9	2,100	21	0.83
S 100	100	130	24,000	9,500	73.1	8,500	65.8	2.100	21	0.79
S 150	150	190	24,000	16,000	84.2	14,400	75.8	2,050	21	0.84
S 200	200	250	24,000	22,000	88.0	19,000	79.2	2,100	21	0.84
S 250	250	305	24,000	27,500	90.2	24.750	81.1	2,100	21	0.84
S 400	400	475	24,000	50,000	105.3	45,000	94.7	2,100	21	0,86
S 1000	1,000	1,095	24.000	140,000	127.9	126,000	115.1	2,100	21	0.84
Diffuse Coated										
S 35/D	35	55	16,000	2,150	39.1	1,935	35.2	1,900	21	0.84
S 50/D	50	70	24,000	3.800	54.3	3,420	48.9	1,900	21	0.81
S 70/D	70	95	24,000	5,400	56.8	4,860	51.2	1,900	21	0.83
S 100/D	100	130	24.000	8.800	67.7	7.920	60.9	2.100	32	0.83
S 150/D	150	190	24,000	15,000	78.9	13,500	71.1	2,100	32	0.83
S 250/D	250	305	24,000	26,000	85.2	23,400	76.7	2,100	32	0.84
S 400/D	400	475	24,000	47,500	100.0	42,750	90.0	2.100	32	0.80
Colour Improved Clear										
150	150	190	7,500	13,600	71.6	12,240	64.4	2,400	65	0.77
200	200	250	7,500	19,000	76.0	17,100	68.4	2,400	65	0.87
250	250	305	10,000	25,500	82.0	22,500	73.8	2.400	65	0.87
Colour Improved Diffuse-Coated										
150	150	190	10,000	13,000	68.4			2,300	70	0.89
250	250	305	10,000	23,000	75.4			2,300	70	0.89
400	400	475	10,000	39,500	82.1			2,300	70	0.89

Direct Replacement of MV Lamps

- Some HPS lamps are designed as direct replacements for MV lamps and use the existing MV lamp fixtures and ballasts.
- In comparison with the MV lamps, the efficacy may be improved by 70%+, but the rated average life is generally shorter.
- Often used in energy conservation retrofits.
- For lamp information, refer to the table below:

Lamp Designation	Lamp Watts	Total Watts Including Ballast I Lamp	Rated Lamp Life (hrs)	Initial Lumens	Initial Lumens per Watt	Mean Lumens	Mean Lumens per Watt	Colour Temp Deg K	CRI	LLD
HPS Operable on Mercury Vapour Ballast **Clear**										
150	150	180	12,000	13,000	72.2	11,700	65.0	1,800		0.85
215	215	250	12,000	20,000	80.0	18,000	72.0	2,060		0.85
360	360	405	16,000	38,000	93.8	34,960	86.3	2,060		0.88
880	880	930	12,000	102,000	109.7	91,800	98.7	2,100		0.67
Phospho-Coated										
150	150	180	12,000	12,000	66.7	10,800	60.0	1,800		0.85
330	330	380	16,000	30,000	78.9	27,000	71.1	2,000	30	0.73
360	360	405	16,000	36,000	88.9	32,400	80.0	2,060		0.88

Notes:
- HPS lamps can be operated in any position without affecting lumen output.
- Life and mean lumen ratings for HID lamps are based on 10 hours per start.

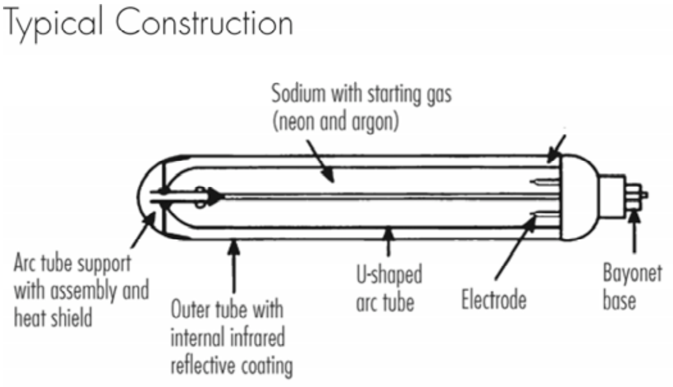
D. LOW PRESSURE SODIUM LAMPS

Construction

- Low pressure sodium (LPS or SOX) lamps are HID lamps, operated at low pressure, in which the arc is carried by ionized sodium vapour.
- LPS lamps are more closely related to fluorescent than HID lamps, since they have a low-pressure, low-intensity discharge source and a linear lamp shape.
- An LPS lamp consists of a U-shaped arc tube enclosed in a clear tubular outer bulb.
- An indium oxide coating on the inside of the outer bulb reflects most of the infrared radiation back to the arc tube.
- The arc tube is enclosed in a vacuum to minimize heat loss.
- The lamp is designed to fully utilize its generated heat.
- The arc tube can maintain an operating temperature of about 2,600°C, resulting in an extremely high luminous efficacy.

Operation

- At start-up, the current is carried by the starting gas (neon and argon) producing a red glow.
- As the lamp warms up, sodium is vaporized and the discharge begins to exhibit the characteristic yellow colour of an LPS lamp.
- Warm-up time is about nine minutes.
- Restrike time is less than one minute.


Typical Construction
Sodium with starting gas (neon and argon)
Arc tube support with assembly and heat shield
Outer tube with internal infrared reflective coating
U-shaped arc tube
Electrode
Bayonet base

Sizes

LPS lamp sizes range from 18 to 180 watts.
Rated Average Life
- SOX 18 – 14,000 hours
- Others – 18,000 hours

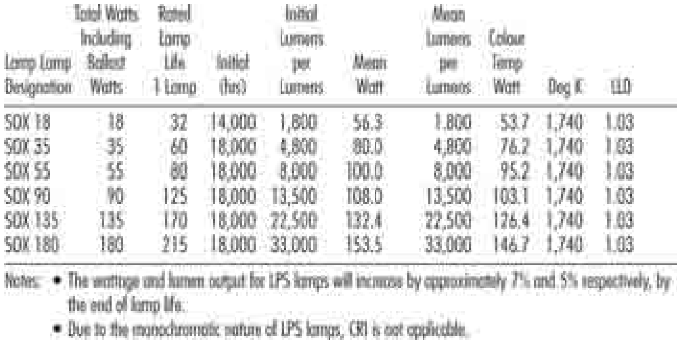
Colour

- The light of an LPS lamp has a yellow colour (monochromatic).
- The colour rendition is very low – it turns every colour to either yellow or muddy brown.
- The CRI value does not apply to this lamp.

Efficacy

- The LPS lamp has the highest efficacy of all light sources.
- Lamp efficacies range from 100 to more than 180 lumens per watt.
- Efficacy increases with lamp size.
- The LPS lamp has the highest efficacy because it emits

monochromatic yellow light close to the peak of the eye sensitivity curve.



Lamp Lamp Designation	Total Watts Including Ballast Watts	Rated Lamp Life 1 Lamp	Initial (hrs)	Initial Lumens per Lumens	Mean Watt	Mean Lumens per Lumens	Colour Temp Watt	Deg K	LLD
SOX 18	18	32	14,000	1,800	56.3	1.800	53.7	1,740	1.03
SOX 35	35	60	18,000	4,800	80.0	4,800	76.2	1,740	1.03
SOX 55	55	80	18,000	8,000	100.0	8,000	95.2	1,740	1.03
SOX 90	90	125	18,000	13,500	108.0	13,500	103.1	1,740	1.03
SOX 135	135	170	18,000	22,500	132.4	22,500	126.4	1,740	1.03
SOX 180	180	215	18,000	33,000	153.5	33,000	146.7	1,740	1.03

Notes:
- The wattage and lumen output for LPS lamps will increase by approximately 7% and 5% respectively, by the end of lamp life.
- Due to the monochromatic nature of LPS lamps, CRI is not applicable.

Applications

- The LPS lamp is generally not used in new construction, but it may be found in existing sites.
- All applications where colour rendering is not important
- Roadway lighting
- Security lighting
- Area floodlighting
- Warehouses

OTHER LIGHT SOURCES

A. INDUCTIVELY COUPLED ELECTRODELESS SYSTEM.

An induction coil is powered by a high frequency generator.

The induced current causes acceleration of charged particles inside the lamp bulb. The metal vapour atoms are excited and ionized causing the release of ultra-violet energy. The UV energy causes the phosphor coating on the lamp wall to glow, creating white light.

- These products are seeing gradual implementation, especially in roadway lighting where long lamp life is beneficial.
- Two major lamp manufacturers have products available.
- These products are proprietary and are therefore not interchangeable.
- They require special sockets and electronic control gear.
- Extremely long lamp life, typically 100,000 hours.
- At present still has high cost.

Icetron from OSRAM/Sylvania		
System Watts	System Lumens	Average Rated Life
107	-6280	100,000
QL Induction Lighting from Philips		
System Watts	System Lumens	Average Rated Life
85	6000	100,000

B. FIBER OPTIC LIGHTING

In a fiber optic lighting system there are a number of components. The illuminator is the active component, containing a halogen incandescent or a metal halide light source, a power supply, and some way of collecting the light into a focused beam. The illuminator may also contain a cooling fan to extend lamp life and a colour wheel or other beam modifying system, so that the light intensity, pattern and colour can be changed. The fiber itself is of either glass or plastic construction, and uses the principal of internal reflection to transmit the light down the length of the fiber.

The fiber may be end-emitting or side-emitting. End-emitting fiber is used by itself or in conjunction with various lenses to give control of the beam. Side-emitting fiber gives a continuous line of light down the length of the fiber and is used for decorative lighting around buildings and swimming pools.

- Fiber optic lighting is not truly a light source, but a method of transmitting light over a short distance.
- Manufacturers have developed more efficient illuminators using Metal Halide lamps and advanced optical reflector designs.

Applications

- Specialty areas where lamp access is a problem, notably pools and display cases.
- Applications where heat from light sources may be detrimental, such as produce displays in a grocery store.

C. LED LIGHTING

General Description

An LED (light emitting diode) is an electro-chemical light source. When the diode is forward-biased, light is generated.

The light is monochromatic; the colour is dependent on the materials used. White light can be produced by using phosphors similar to those used in fluorescent and coated HID lamps.

Efficacy

The efficacy of LED sources is improving continuously; currently about 30 lm/W is typical.

Life

Lamp lumen depreciation in a light source is the gradual reduction in light output over time, caused by normal deterioration of phosphors, cathodes, filaments and the other components of the system. LED systems last up to 100,000 hours, based on the fact that when the light output has depreciated to less than 50% of initial output, then the light source has effectively expired. Life of LED systems is dependent on a number of factors including the colour; red and green LEDs last significantly longer than blue and white LEDs.

Advantages

- Low power consumption and low heat generation.
- Extremely long life.
- Negligible early failures.
- High colour efficiency, because they are monochromatic.
- Very small.
- Resistant to damage from shock and vibration.
- No infra-red or ultra-violet energy is emitted.

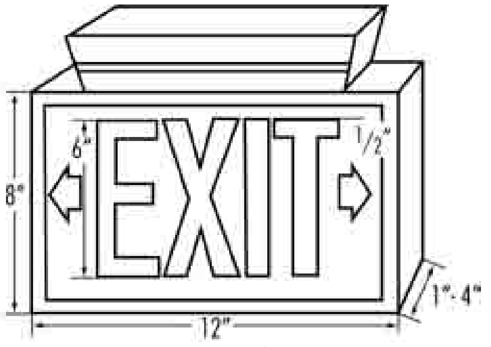
Applications

- Typically used in exposed source applications such as signage, decorative festive lighting, marketing displays, and automotive applications
- Traffic signal lamps
- Exit signs
- Seasonal light strings

EXIT SIGNS

PHYSICAL DATA

- Most exit signs are approximately 12" long, 8" high and between 1" and 4" in depth.



Physical Dimensions of a Typical Exit Sign

Types of Signs

There are two types of exit signs:

- externally lit (rare)
- internally lit (most common).

Externally Lit

- An external light is aimed on the sign.
- Bulb replacement is easy.
- Sign is difficult to see in smoky conditions.
- Power consumption is high (generally incandescent lamps are used).

Internally Lit

- Single- or double-sided sign with light source inside the fixture.
- Some exit signs have an opening fitted with a diffractive lens at the bottom to help light the exit route.

Light Sources of Internally Lit Signs

There are four light sources for internally lit exit signs:

- Incandescent lamps
- Compact fluorescent lamps
- Low-voltage lamps: LED and miniature incandescent lamps
- Tritium gas (Tritium gas signs do not meet current code requirements for brightness of internally lit signs. Consult your lighting designer.)

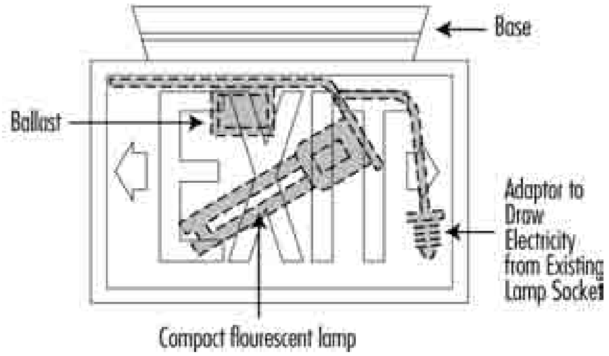
LED Signs

- LED (light emitting diode) type sign has LEDs in plastic tubes which form the letters.
- These signs use plastic as the medium to transmit the light.
- Require less depth than incandescent and compact fluorescent signs.
- More uniform illumination of letters.
- Manufacturers expect 10- to 15-year lamp life.
- Consumes approximately 2 to 3 watts of power.

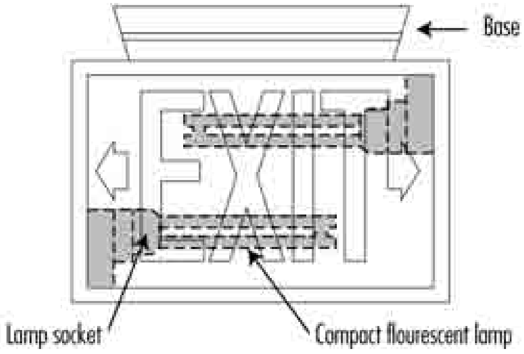
Compact Fluorescent Signs

- More expensive than incandescent signs.
- Most incandescent exit signs can be retrofitted with compact fluorescent if there is sufficient space inside the sign to accommodate the lamp and the ballast, although this has become an unusual practice due to the efficiency of LED retrofit units.

Compact Fluorescent Lamp Retrofit Lamp



Compact Fluorescent Lamp - Hard-Wired



- Compact fluorescent lamps of 5, 7 and 9 watts provide lighting levels similar to incandescent lamps of 25, 40 and 60 watts respectively.
- Lighting of each letter is not uniform.
- Lamp life is generally one to two years.
- Consumes approximately 12 to 20 watts.

Tritium Gas Signs

- Illumination principle is similar to that of a television.
- Radioactive tritium gas undergoes beta decay, releasing an electron which is incident on a phosphor-coated tube, shaped into the word EXIT
- A modern tritium exit sign uses 25 curies (about 2.5 milligrams of tritium in the gaseous form).
- No external energy source required.
- Lamp life is 10 to 20 years; it must then be replaced.
- Highest capital cost for lamp and fixture.

Incandescent Signs

Existing incandescent signs should be immediately replaced because of cost of operation and in commercial and industrial applications cost of maintenance.

- Can no longer be purchased in Canada.

- Incandescent signs usually have two 15 to 25 watt bulbs.
- During a power failure, a sign may be energized by either the emergency power supply system or a 12 V bulb in the middle of the sign powered by a battery.
- Cost varies due to construction features such as vandal-proofing, internal battery etc., and aesthetic features.
- Incandescent signs were the most common type of exit sign in the past.
- Lighting of each letter is not uniform.
- Bulb life is generally one to six months.
- Consumes approximately 30 to 50 watts of power.

Code Requirements

- The National Building Code of Canada requires that:
  "Lettering on exit signs shall be:
  (a) red letters on a contrasting background or white letters on a red background, at least 114 mm high with 19 mm stroke spelling EXIT or SORTIE when the sign is internally illuminated, and
  (b) white letters on a red background or red letters on a white background at least 150 mm in height with 19 mm stroke spelling EXIT or SORTIE when the sign is externally illuminated.

  "The lighting for exit signs shall:
  (a) be supplied by an electrical circuit that
  (i) is separate from the other circuits, or
  (ii) serves other emergency equipment, and
  (b) be connected to an emergency power supply..."
- The National Fire Protection Association of the United States requires the exit signs "... be illuminated by not less than 5 foot candles (54 lx) and shall employ a contrast ratio of not less than 0.5".

  This is not a requirement in Canada.

Assessment

- Incandescents are inexpensive to purchase but expensive to operate and maintain.
- Compact fluorescents can be retrofitted into most incandescent fixtures to reduce energy and maintenance costs.
- LED signs consume less electricity and provide more uniform illumination, as well as being more aesthetically pleasing.
- Tritium gas signs do not consume electricity. The energy comes from the radioactive decay of tritium. They have a high initial cost but require very little maintenance.
- The energy efficiency of Exit Signs are now regulated in Canada and LED technology is the only one able to meet these performance levels.

EMERGING TECHNOLOGIES

REDUCED SIZE SOURCES

- An area of continuing research and development is reducing the size of efficient light sources. Very small, T4.5 39 W ceramic metal halide lamps are presently available, and smaller lamps are being developed.

White Light LEDs

- The LED segment of the market is growing and is believed to be the technology of the future for lighting; efficient, long-life white light LEDs in convenient packages, such as a medium screw base lamp module, could replace traditional incandescent lamps.

Lighting Controls

- While outside the scope of this publication, significant research is being carried out in the area of lighting controls, to allow better and more consistent dimming of sources such as low wattage metal halide, compact fluorescent and LED lamps.

Intelligent Ballasts

The universal adoption of electronic fluorescent ballasts has lead to the development of intelligent ballasts incorporating dimming with addressability of individual ballasts. The DALI (Digital Addressable Lighting Interface) protocol allows users and building operators to combine luminaires into control zones in software, thereby eliminating costly rewiring whenever a tenant changes a partition location. In combination with photocells and occupancy sensors, the lighting system becomes a proactive element in the building to optimize the control of illuminance levels.

CODES, STANDARDS AND REGULATIONS

Adherence to the appropriate codes and standards is best achieved by following the recommendations of a qualified lighting specialist. There are considerable revisions and changes which will continue to evolve both at the national and provincial/state level. For example, the Canadian Federal Energy Efficiency Act of 1992 provides for the establishment and enforcement of regulations concerning minimum energy performance levels for energy-using products. The act also enforces labeling of energy-using products as well as the collection of data on energy use. These regulations refer to many industry testing and performance standards, and are administered in Canada by Natural Resources Canada (NRCan) www.oee.nrcan.gc.ca. These regulations apply to regulated energy-using products imported into Canada or manufactured in Canada and shipped from one Province to another. It is important to consult the acts and regulations which are enforced in your jurisdiction.

There is also the Energy Policy Act of 1992, an amendment to the Energy Policy & Conservation Act that was passed in 1975. It included provisions for utilities to invest in conservation and energy efficiency, as well as funding for establishing energy efficient lighting and building centers.

There are further enhancements expected that have resulted from the realization and support for energy efficiency.

CODE FOR BUILDINGS

Similarly, it is important to remain current on local and regional requirements. There are often references to national codes or standards, but may also be enhanced requirements.

Examples of national efforts include:

- Residential buildings: Council of American Building Officials (CABO) Model Energy Code.
- Commercial Buildings: ASHRAE/IESNA standard 90.1-2004.
- Guide to Canada's Energy Efficiency Regulations – Natural Resources Canada, 1999.

WORKSHEETS

LIGHTING COST AND SAVING ANALYSIS

A. AN AUDIT DATA WORKSHEET

PROJECT SUMMARY		
Project:	Project Manager:	
Site:	Project Engineer:	
Report:	Lighting Specialist:	
Total Area (sq.ft.):	Lighting Designer:	
Date of Report:	Regional Office:	
Rev.:		
Project No.:		
Building No.:		
COST AND SAVINGS ANALYSIS		
Existing Electrical Use – (Base Year Electrical Data):		
Annual Electrical Demand – Peak Average: (kW)		
Annual Electrical Consumption:		(kWh)
Annual Hours of Use (Average):		(hrs.)
Annual Electrical Cost:		($/sq.ft.)
Electrical Rates Information		
Blended Rates	Summer	Winter
Demand Charge (kW) – ($)		
Consumption Charge (kWh) – ($)		

Lighting Energy Savings Summary				
	Demand	**Electrical Consumption**	**Cost**	**Cost/sq.ft.**
	(kW)	(kWh)		
Current Usage	0.0	0	$0	
Proposed Retrofit	0.0	0	$0	
Savings	0.0	0	$0	

Lighting Cost and Savings Summary			
Item	Cost	Cost/sq.ft.	
Outside Materials Cost	$0		[Calculated + Adjustments]
Outside Labour Cost	$0		[Calculated + Adjustments]
Total Outside Cost	$0		[Sum Above 2]
Outside Service Markup (17.0%)	$0		[Cost Multi. + % Noted – Calc. Cost/sq.ft.]
Rose Technology Labour (15%)	$0		[Cost Multi. + % Noted – Calc. Cost/sq.ft.]
Subtotal	$0		[Sum Above 3]
Guarantee (0.0%)	$0		[Cost Multi. + % Noted – Calc. Cost/sq.ft.]
GRAND TOTAL – COSTS	$0		[Sum Above 2]
Lamp & Ballast Savings	$0		[User Entry + Calc. Cost/sq.ft.]
Utility Incentive	$0		[User Entry + Calc. Cost/sq.ft.]
Annual Savings	$0		[From Above + Calc. Cost/sq.ft.]
GRAND TOTAL – SAVINGS	$0		
Simple Payback (years)			[Total Cost/Total Savings]

PROJECT NOTES

NOTES: (a) Standard voltage (120 V) and lamps (34 W/40 W) existing. [User entry]

(b) Demand charge and consumption rate see chart below. [User entry]

(c) Handling of P.C.B. ballasts not included in project cost. [User entry]

(d) Asbestos content taken into account. [User entry]

(e) Highlighted areas represent altered design due to asbestos conditions. [User entry]

LIGHTING BASICS

Erik Bouts, President & CEO of Philips Lighting

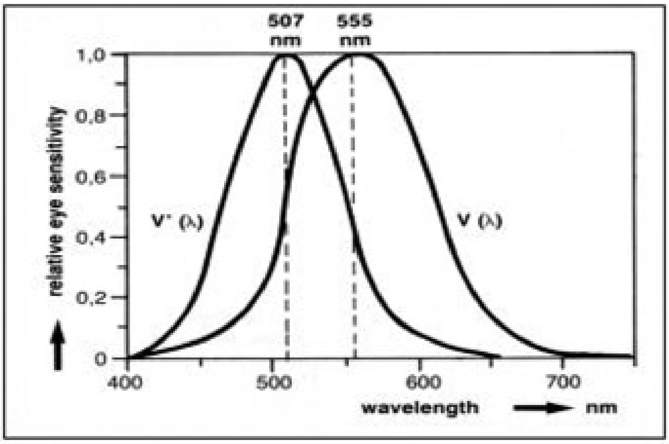
LIGHTING UNITS

CONCEPTS OF PRACTICAL LIGHT MEASUREMENT

There are four basic concepts of practical light measurement

Quantity	Symbol	Unit
Luminous Flux	_/P>	lumen
Luminous Intensity	I	Candela
Illuminance	E	Lux
Luminance	L	Candela per square metre (cd/m2)

When considering light which is visible electromagnetic radiation, we are concerned on the one hand with energy and the other with a sensation obtained through the eye. These two are principally dissimilar things. That makes it difficult to talk about light in quantitative terms. To solve the problem, a convention has been adopted that fits in well with illuminating engineering practice: viz. the product of radiant energy and eye sensitivity. Thus, light is regarded as radiation measured in terms of human eye sensitivity.



THE LIGHT WATT:

The sensitivity of the eye varies with wavelength of light. Under conditions of photopic (Day time) vision, the maximum sensitivity lies at 555nm. Now one could choose to define one watt of power radiated at a wavelength of 555nm as being equal to one 'light-watt'. One watt of power radiated at a different-wavelength within the visible range would then have to be multiplied by the relative eye-sensitivity factors as defined by the spectral eye sensitivity curve for photopic vision, that is to say the V(l) curve. By so doing, one arrives at the light-watt value corresponding to that wavelength. For example, for radiation with a wavelength of 490nm, the eye sensitivity is only 20 per cent of that for radiation with a wavelength of 555 nm. One watt of power radiated at 490 nm therefore equals 0,2 light-watts.

At low lighting levels, the sensitivity of the eye shifts left (ie., towards shorter wavelengths) with the peak sensitivity at 507nm. This is called scotopic vision.

THE CANDELA:

By adopting the light-watt as the unit of visible radiation for the quantitative expression of visual perception, ambiguity would have been completely avoided. However, this concept was not adopted because, long before it was even formulated, a light unit had already been derived from one of the earliest reproducible lighting standards. This standard was the 'candle power' which became (after 1948) the 'candela'. It was, in fact, a unit of light intensity in a given direction. A light source radiating a light intensity of one candela in all directions produces a well-defined quantity of light per second, which has been given the name 'lumen'. This has become the principal lighting standard in use today.

MAXIMUM SPECTRAL LUMINOUS EFFICACY

Calculations have shown that one watt of radiant power with a wavelength of 555nm equals 683 lumens. This figure is known as the 'maximum spectral luminous efficacy'. Thus, one watt of power radiated at 490 nm equals0,2 x 683 = 137 lumens.

The lumen can therefore be defined as a certain quantity of radiant energy emitted per second, weighted against the spectral sensitivity of human eye.

THE COSINE LAW

The illuminance at a point in a plane not perpendicular to the direction of the luminous intensity is equal to the luminous intensity in the direction of the point, divided by the square of the distance between the light source. It has to be multiplied by the cosine of the angle g that the direction of light incidence makes with the perpendicular to the plane. Thus:

$$E_p = \frac{I \cos^2}{d^2} \gamma$$

This is called the Cosine law.

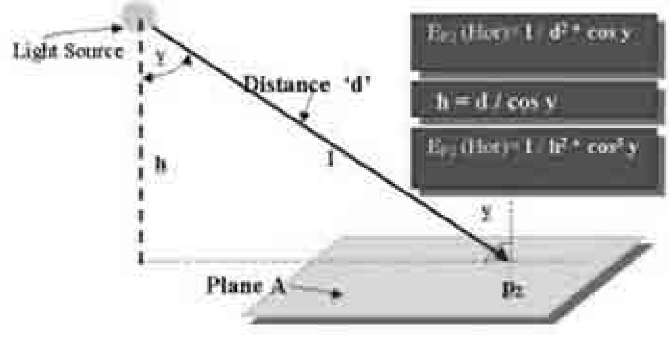
For horizontal surface, it will often be more practical to modify the above formula by replacing the distance (d) between the light source above the surface, as a function of its height h.

If the ray of light is not reaching perpendicular to the plane but at an angle g, the result is the formula.

$$E_{hor} = \frac{1}{h^2}\cos^3\gamma$$

VERTICAL ILLUMINANCE

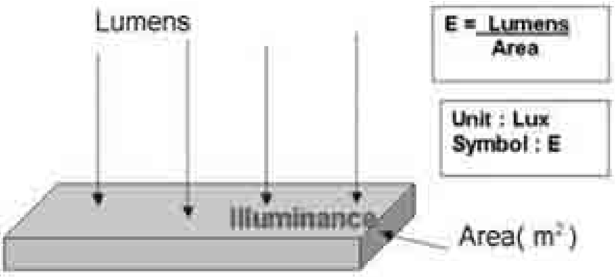
On similar reasoning, the vertical illuminance at that point will be



DEFINITION OF ILLUMINANCE

Illuminance – symbol E, unit lux (lx)

Illuminance is the quantity of light, or luminous flux, falling on unit area of a surface. It is designated by the symbol E. The unit is the lux. One lux equals one lumen per square metre (lm/m2).



ILLUMINANCE CAN BE DEFINED AS:

The ratio of the luminous flux incident on a surface to the area of that surface.

$$E_{ver} = \frac{1}{h^2}\cos^2\gamma\ \sin\gamma$$

The Illuminance is independent of the direction from which the luminous flux reaches the surface.

Some practical examples:

Summer, at noon, under a cloudiness sky	100 000 lux
Ditto, but in the shade	10 000 lux
In the open under a heavily-overcast sky	5000 lux
Artificial light, in a well-lit office	1000 lux
Artificial light, average living-room	100 lux
Street lighting	5-30 lux
Full moon, on a clear night	0,25 lux

DEFINITION OF LUMINANCE

Luminance – symbol L, unit candela per square metre (cd/m2)

Luminance is the concept for the luminous intensity emitted per unit of area of a surface in a specific direction. The surface can itself be light-emitting, or transmitting – like the surface of a lamp or the sun - but it can also reflect light from another source (like a road reflecting light from a streetlight and thus act as a secondary light source). It is designated by the symbol L. The unit is candela per square metre (cd/m2).

$$E = \frac{\varnothing}{A}$$

LUMINANCE CAN BE DEFINED AS:

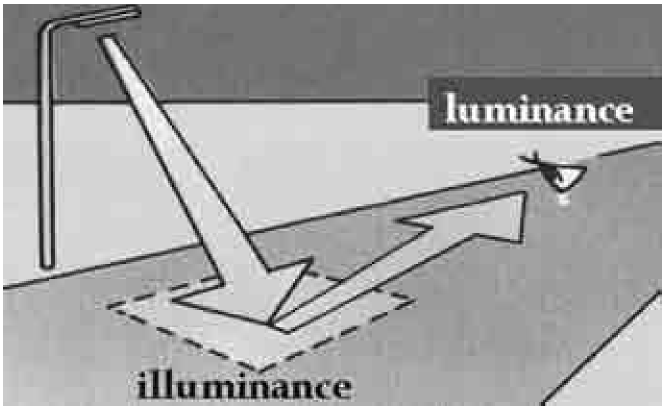
The ratio of the luminous intensity from a surface in given direction to the apparent area of that surface.

Apparent area are different for different viewing angles

By apparent area is meant the projection of the area of the surface in question on a plane that is at right angles to the direction of view. For a sphere, for example, the total apparent area in any direction is the area of the cross-section of the sphere.

Surfaces with different reflecting properties will, with the same illuminance, radiate different luminous intensities, and therefore have different luminance.

As both the luminous intensity and the apparent area are independent of distance, luminance is also independent of distance. On the other hand, luminance is generally dependent on the direction of observation, unless the surface has perfectly diffuse reflecting or emitting properties.



THE MOST IMPORTANT LIGHTING QUALITY

What we really 'see' in life are luminances, or rather luminance variations in the field of view. It is, therefore, the most important quantity in lighting engineering, although the other three – luminous flux, luminous intensity and illuminance – are generally easier to work with when performing calculations or measurements.

Some practical examples:

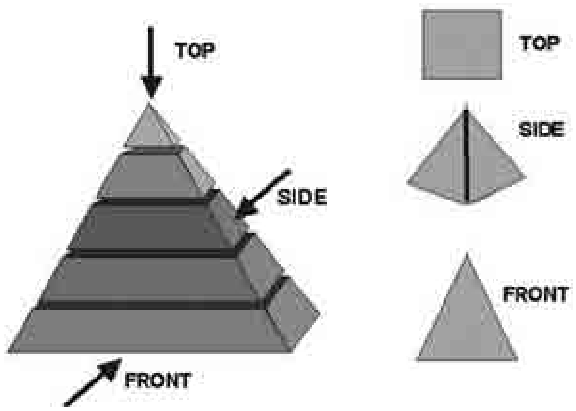
Surface of the sun	1 650 000 000 cd/m2
Filament of a clear incandescent lamp	7 000 000 cd/m2
Bulb of an 'Argenta' incandescent lamp	200 000 cd/m2
Fluorescent lamp	5000 – 15 000 cd/m2

Surface of the full moon	2500 cd/m2
Sun-lit beach	15 000 cd/m2
White paper (reflectance 0,8) under 400 lux	100 cd/m2
Grey paper (reflectance 0,4) under 400 lux	50 cd/m2
Black paper (reflectance 0,04) under 400 lux	5 cd/m2
Road surface under artificial lighting	0,5 – 2 cd/m2

DEFINITION OF LUMINOUS FLUX (OR LIGHT OUTPUT OF A SOURCE)

Luminous flux – symbol f, unit lumen (lm)

Luminous flux is the concept for the total quantity of light emitted per second by a light source. It is designated by the symbol f. The unit is lumen (lm).



LUMINOUS FLUX CAN BE DEFINED AS:

The energy radiated by a light source per second, weighted against the spectral sensitivity of human eye.

Some example of practical light sources:

Bicycle headlamp	3W	30 lm
Incandescent lamp	Argenta75 W	900 lm
Compact fluorescent lamp	Essence14W (WW)	800 lm
Fluorescent lamp	'TL'D36 W/84	3350 lm
High-pressure sodium lamp	SON-T100W	10000 lm
Low-pressure sodium lamp	SOX-E130W	26000 lm
High pressure mercury lamp	HPL-N1000W	58000 lm
Metal halide lamp	HPI-T2000 W	190000 lm

LUMINOUS EFFICACY

As becomes clear from the above table, there is no fixed relationship between the electrical energy dissipated in a lamp and the luminous flux radiated. The ratio between luminous flux and power dissipation is called 'luminous efficacy' and is expressed in lumens per watt (lm/W). Each lamp type has its own specific luminous efficacy.

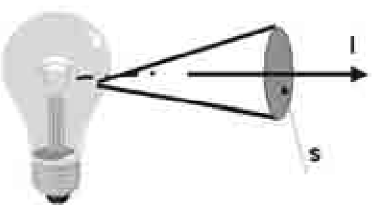
DEFINITION OF LUMINOUS INTENSITY

Luminous intensity – symbol l , unit candela (cd)

Luminous intensity is the concept for the concentration of light in a specific direction, radiated per second. It is designated by the symbol l. The unit is the candela (cd). The luminous intensity can be defined as: the luminous flux in a certain direction, radiated per unit of solid angle (steradian).

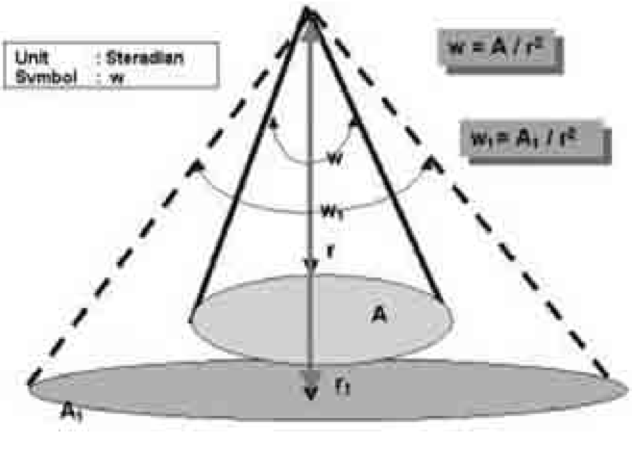
This brings us to the concept of the solid angle, and its unit: the 'steradian'. A solid angle can best be described as a measure for a portion of space around a point bounded by the surface of a cone whose top (vertex) is at the point.

In general a light source will not radiate its luminous flux uniformly in all directions. If, however, we imagine a sufficiently narrow cone, with its vertex at the light source (which is considered as a point), then the luminous flux contained in this cone will approximate a uniform distribution. The concentration of luminous flux within this narrow cone can now be defined as the luminous flux in this cone, divided by the opening of the cone, expressed in terms of the solid angle of the cone. The result is called the luminous intensity (l), measured in candelas (cd), in the direction of the center-line of the cone.



A STERADIAN IS A MEASURE FOR A SOLID ANGLE

The size of the solid angle is expressed in a similar manner as with a plane angle, either in degrees or radians. Imagine a sphere of arbitrary radius (r), with the top of the cone as its center. The part of the surface of the sphere which is enclosed by the cone is then proportional to the solid angle (w) of the cone. If the area of the surface of the sphere covered by the cone is equal to the square of the radius (r2), then the corresponding solid angle is termed a 'steradian'. So, if the enclosed area of the surface of the sphere is not equal to r2 , but is, say, equal to A, then the solid angle $\omega = \frac{A}{r^2}$ steradians.



A WHOLE SPHERE CONTAINS 4P STERADIANS

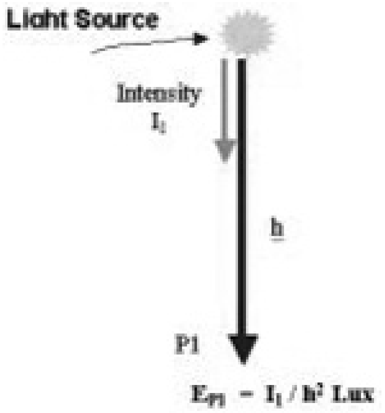
The maximum possible solid angle will enclose a whole sphere. As the surface of a sphere of radius r is 4pr2 , this solid angle will be equal to $\frac{4\pi r^2}{r^2} = 4\pi$ steradians

Hence, a half-sphere will contain 2p steradians.

The concept of luminous intensity is of tremendous importance in lighting technology, as virtually no piece of lighting equipment emits its luminous flux equally in all directions. This quite deliberately so, for some directions are far more important to the observer than others, and some even have to be avoided (glare!). The luminous intensity distribution of a lamp or luminaire, therefore, gives a good indication of its practical luminous efficiency and area of application.

Bicycle headlamp without reflector, in any direction	2,5cd
Bicycle headlamp with reflector, centre of beam	250cd
Incandescent reflector lamp PAR38E Spot 120W, centre of beam	10 000cd
Lighthouse, centre of beam	2 000 000cd

THE INVERSE SQUARE LAW



Relation between luminous intensity (l) and illuminance (E)

The illuminance on a point in a plane perpendicular to the direction of light incidence is equal to the luminous intensity in that direction divided by the square of the distance between the light source and the point in question. If we call this distance h, the following formula applies:

$$E_p = \frac{1}{h^2}$$

For example, if a point light source emits a luminous intensity of 100cd in a direction perpendicular to a surface at a distance of 3 metres, the illuminance (Ep) at the point where the light strikes the surface will be 100/32 = 11 lux. If the surface is at a distance of metres from the light source, the illuminance will be: 100/22 = 25 lux.

This relationship is called the ‘inverse square law’. Strictly speaking, it is only valid for point sources. In practice, however, the law holds good approximately as long as the distance between the light source and point of calculation or measurement is more than three times the longest dimension of the light source. For laboratory measurements on luminaires, on the other hand, the distance should be at least five to ten times the longest dimension of the luminaire.

RELATION BETWEEN LUMINOUS FLUX (F) AND LUMINOUS INTENSITY (L)

The luminous intensity in any direction of light source whose light distribution is uniform in all directions, is equal to the luminous flux divided by 4π

Thus:

$$I = \frac{\phi}{4\pi}$$

For example, an incandescent lamp of 2000 lumens, fitted in a globe luminaire of opal glass with a transmittance of 0,9 will (approximately) have in any direction a luminous intensity of:

$$\frac{2000 \times 0{,}9}{4\pi} = 143 \text{ cd}$$

This radiation is only of limited practical importance, as it is only valid for light sources that radiate equal luminous intensities in all directions.

ENERGY SAVING

Energy consumption is a key decision factor for any lighting solution. Knowing that lighting represents up to 30% of a building's energy consumption, it is clear that remarkable savings in operational cost can be achieved with a good lighting design.

ENERGY SAVINGS CAN BE ACHIEVED IN DIFFERENT WAYS:

- Converting standard lamps and/or conventional gear for energy friendly lamps and/or HF ballasts in existing lighting installations
- Complete and integral (renovation) project.

It is clear that re-doing the lighting installation normally generates the highest energy savings but many times even a re-lamping exercise can lead to significant cost reductions.

ALL CRITERIA FOR LIGHTING SYSTEM COMPONENTS ARE LISTED BELOW

Lamps

Selection criteria

To achieve maximum savings one should select the range of lamps that meet the quality requirements such as colour properties, light intensity, etc and then choose the lamp which has the highest efficacy within the group. Selection criteria are:

- Luminous efficacy of lamps (lm/W ratio ? the higher the better)
- Luminous flux and lumen depreciation over time
- Damage factor
- Colour parameters (colour rendering, colour temperature, colour shifting)
- Average lamp life

Well known energy saving lamps with superior lighting qualities and life times:

- Compact fluorescent lamps instead of incandescent lamps
- ‘TL’D Super /80 New Generation series instead of standard ‘TL’ lamps
- ‘TL’5 lamps instead of standard ‘TL’ lamps
- MASTERline ES halogen lamps instead of standard halogen lamps
- Mastercolour lamps instead of halogen lamps
- HPI lamps instead of SON-T lamps

Control Gear

Selection criteria

- Ballast loss
- Harmonic considerations
- Effects of the control gear on the lamp

Range

- High frequency electronics gears
- Super low loss ballasts

Luminaire

Selection criteria

To achieve maximum savings, one should select the range of lamps satisfying the quality requirements such as colour properties, etc. and then select the lamp which has the highest efficacy within the group. Criteria to be considered:

- Light output ratio
- Optical systems (reflectors, louvres, etc.) and their distribution

Range

- High efficiency OLC optics for indoor offices
- POT optics for road lighting

Osram Sylvania Ltd.
2001 Drew Road
Mississauga, Ontario
L5S 1S4
Tel: (905) 673-6171
Fax: (905) 671-5584
E-Mail:www.sylvania.com/ContactUs/AskaQuestion
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OSRAM SYLVANIA is one of the leading lighting manufacturers in the world. With Canadian headquarters in Mississauga, Ontario, OSRAM SYLVANIA LTD. provides innovative and environmentally responsible lighting products and systems that provide increased efficiency without sacrificing quality of light. Our products include; compact fluorescent, fluorescent, halogen, metal halide and high pressure sodium lamps, as well as LEDs and high efficiency electronic ballasts.

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Philips Canada
281 Hillmount Road
Markham, Ontario
L6C 2S3
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Canada is a key market for Philips and Philips enjoys a strong presence there. The divisions operate independently, yet coordinates closely in sharing technologies and in developing products for the consumer and business-to-business marketplaces. Under the leadership of the Corporate Center in Amsterdam, this collaboration is required to unlock the full potential of the Philips brand.

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4011 14th Avenue
Markham, Ontario
L3R 0Z9
Tel: (905) 940-0888
Fax: (905) 940-0338
E-mail: general@ultrasave.ca
Web: www.ultrasave.ca

Ultrasave is located in Markham, Ontario. Headed by a design engineer with over 20 years of experience in electronic ballast circuit design, our prime lab is equipped with the latest measurement instruments and power supplies. Our factory research and development lab, located in Taiwan, is headed by a leading design engineer responsible for numerous ballast designs and has more than 20 years experience in this field. Currently, all Ultrasave ballasts are manufactured by our offshore ISO 9001/9002 certified factories. These facilities also supply electronic ballasts under private labels to well-known corporations within the lighting industry throughout Europe, North America and Japan.

SAVES UP TO 50% ON ENERGY

Full Range of Linear Fluorescent Ballasts for High Bay Fixtures:

T5HO BALLASTS

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- Multi-V 120-277V, dedicated 347V
- 4 or 6 lamp options
- Terminal or wire connections
- <20% THD, >0.99 PF
- Lamp EOL protection circuit
- 90˚C case temperature rating
- 54W T5HO lamp
- cULus approved

T8 HIGH EFFICIENCY BALLASTS

- Instant start
- 0˚F/-18˚C starting capability
- Multi-V 120-277V, dedicated 347V
- 6 lamp option
- Parallel lamp operation
- <10% THD, >0.99 PF
- 1.18 high ballast factor
- 90˚C case temperature rating
- 32W T8 lamp
- cULus approved

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- HID lamp with integrated electronic ballast is an instant retrofit from halogen PAR38
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- Provide 95% lumen maintenance and 85 CRI
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